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## THE LIFE-HISTORY OF STAR SYSTEMS.*

HENRY L. CLARKE.

FOR POPULAR ASTRONOMY.

A third of a century has passed since the law of evolution found its first definite expression in Darwin's "Origin of Species;" and we have watched that law irresistably broaden its influence until it has become the whole inspiration and philosophy of the scientific spirit of today. Significantly, the biological sciences were the first battle-field of modern evolution, and still remain the most prominent subject matter in evolutionary controversy. It has been in the part of nature that is nearest kin to man's own conscious life, in the living animal and the living plant, that we have first tried to study the working of a law whose expression, we have come to realize, is the whole of nature, the physical no less than the organic. But the complexity of characters and processes in the animal and the plant worlds, and the obviously undefined gradations in those characters and processes,—these facts taken together, though serving the vital end of emphasizing the law of evolution as a law of continual change, of progressive action, baffle attempts to outline in clear definite form and terms the working method of evolution, and to define the aspect of "change" in the process through reference to the other aspect, that of relative "fixity." The result to modern scientific thought is the confusion of speculative absurdity that is masquerading in much of our biological literature as professedly scientific study of life-development. A reaction of inestimable importance is the turning of attention to the study of evolution in the realm of the physical sciences where the clearly-conceived, definite subject-matter, with the absence of vague detail, must mean the treatment of problems from the exact standpoint of the higher mathematics. Thus exactness of statement takes the place of the speculative indefiniteness to which the extreme of

* An outline study of an aspect of *physical* evolution, made in the course of preparing material for a special study upon a certain problem in *general* evolution.

NOTE.—The writer is indebted to Professor E. E. Barnard, Professor S W. Burnham and Dr. T. J. J. See for the photographs and drawings used in the preparation of nearly all of the illustrations that accompany the text.

purely biological investigation has led,—an exactness that by itself is too ideal to give us truth, but that taken together with the valid observations of biology can yield a definite yet realistic notion of evolutionary principles. The physical science whose concepts have, pre-eminently, ideal exactness is mathematical astronomy; and from the province of mathematical astronomy there has come, within a few years past, a contribution to knowledge that, rightly understood, marks an epoch in the history of evolution. The first great step in this new direction was taken scarcely a decade ago by—strangely enough—George Darwin, son of the Charles Darwin whose genius had raised the great wave of evolutionary study in modern biology. Father and son, biologist and mathematical physicist, from widely different standpoints in natural science have made complementary interpretations of a common law whose broad outlines the elder Darwin first clearly stated. The work of George Darwin has been a scholarly contribution to the theories of the development of the solar system. His highly theoretical treatment of the subject has been the starting point; the practical application, and the broad generalizing of the problem to affect the star systems in remote space have been accomplished by the American astronomer, T. J. J. See, partly by original discovery, partly by elaboration of the Darwinian results. A plain summary of the general results is the end here in view, with special emphasis on their meaning for our knowledge of general principles of evolution. And the reaction of those principles upon the data and method of the higher astronomy will be a final question of peculiar interest for the future of the physical sciences.

Speculation on the beginnings of the solar system is as old as the philosophers of ancient Greece; but anything that could be called speculation in the true spirit of science is comparatively recent. Kant turned the fire of his philosophical genius on the problem and gave to the world a theory that was a curious mixture of sound science—the product of his broad practical conception of natural law, and philosophical mysticism—the stamp of his idealizing powers. It remained for Laplace to outline the speculation that, partly through its own rational force, partly on the authority of so great a mind as that of its author, became the creed of science, in this special field, for almost an entire century. Exactly one hundred years have passed since the "nebular hypothesis" was published as a closing note to Laplace's "Systême du Monde;" and few speculations of science have ever exercised as broad and as deep an influence upon gen-

eral thought. The centennial anniversary is an appropriate time to look back for a moment and consider what the spirit of the "nebular hypothesis" meant to science; and then to review in plain general terms the revolutionary changes that in the last fifteen years have remade that hypothesis in accordance with new principles and a new spirit of scientific thought. In contrast to the belief of Sir Isaac Newton that the planets had been made and placed in their paths by the direct act of Diety, there is much in Laplace's theory that seems a foreshadowing of the modern conception of all the parts of nature as the product of developmental change. But there is also a vital difference between Laplace's point of view and ours. The great monumental work that he left to the world was not the "nebular hypothesis"—that was only a minor incident—but the *Mécanique Céleste*, the immortal record of a life-time's labor, of almost the greatest mathematical mind of all the ages, in formulating the exact motions of the heavenly bodies. And the whole spirit of the *Mécanique Céleste* is that of rigorous mathematics. "The laws of celestial mechanics are eternal" was the creed of Laplace; the motions of planets and satellites change, but the changes are periodic; the periods may be days or centuries or immeasurable ages, but always there is the certainty of return to the starting point in the due lapse of time. And he was right—as far as he went. The great work that he left with that principle as its text has been and is of untold value to astronomy; but as many another man of genius has done, his deepest insight into natural law he left us in a footnote. His was too great a mind not to preceive that, although the practical limits of his knowledge forced him to treat the observations of astronomy from the ideals of rigid mathematics, nevertheless there had been and were changes going on that could not be translated into eternally repeating periods, that really meant the world-system of yesterday would never be exactly repeated at some future to-morrow. Suggestions of this truth appear here and there in the *Mécanique Céleste*, and on the closing pages of the *Système du Monde* we find one definite application and express statement of his conception of development, of growth-change. He knew that the Sun was a cooling body, and he realized that tracing back its history indefinitely far we must somewhere reach a period when its character was vastly different from what it is now, in order to account for all the heat that it has radiated into space through all subsequent time; he surmised that then the condition of the Sun must have approached that of the highly rarefied gaseous nebulæ that the telescope revealed as

filmy patches of luminous cloud everywhere in space. And when the Sun was thus expanded into a vast nebula, greater than the whole solar system in extent, it was inconceivable that the system of planets should have existed. Therefore it was in the highest degree probable that as the nebulous Sun cooled and contracted, and as a result of contraction was set in violent rotatory motion, its figure became unstable, parts of it were separated from, and abandoned by, the great central mass, and these parts condensed into planets, which in turn developed systems of satellites about themselves; and thus originated the eternal and ideally perfect complex of motions in the solar system. True to the modesty of an intellect that knows the practical limits of existing knowledge, Laplace did not try to formulate a single stage of this history in mathematical terms. To say that he could not have done it if he had had the data we possess today is but absurdity, for we can repeat now with almost literal truth the famous words Baron Fourier uttered a half-century ago,—"Laplace would have completed the science of the skies, if that science could be completed!" He knew that this speculation had in it scarcely an element of scientific exactness, and he did not pretend that it was more than the broadly general outlines of a working hypothesis that might help to guide future deeper research. One fundamental clause he based upon an article of faith in the theoretical physics of his day that has proved to be imperfect; and that one clause, though accepted without question for over three quarters of a century, has led to endless blind discussion in recent years, and seems destined to be finally swept aside. He did not know that a rotating half-fluid mass could assume any other form than one of perfect radiate symmetry around its axis of rotation. He therefore reasoned that the rotating condensing Sun, flattening at its poles and bulging at its equator, would shed successive equatorial rings of matter; that each ring, abandoned as the Sun contracted, would revolve as a whole at the same distance from the Sun's centre as the orbit of the planet that the ring was destined to form. Then finally the necessary irregularity of such a ring would cause it to break and somehow condense its matter into a planet rotating and revolving in the same direction, and tracing the same path, that the ring had revolved in. The "somehow" was the problem that has had to be left unsolved. But as an apparent monumental witness for just this process he could point to the rings of Saturn; and that argument carried conviction with it until less than a dozen years ago. Passing this detail for the present, it

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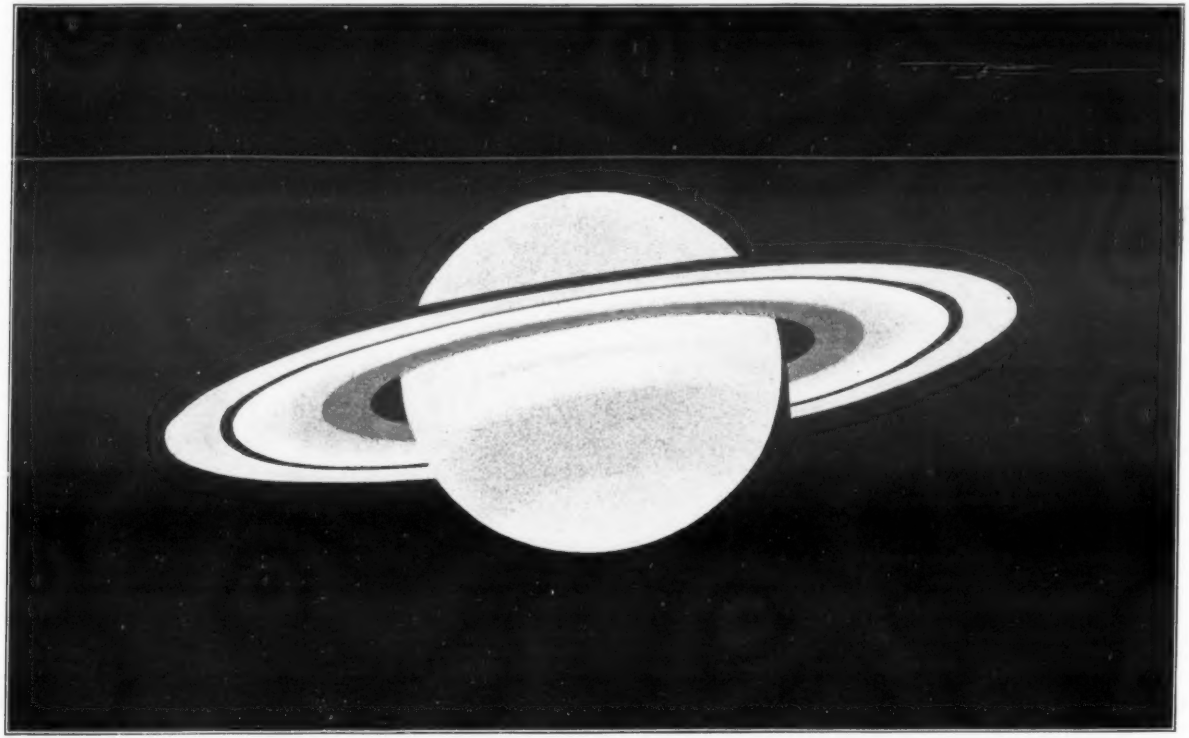
PLATE XIX.



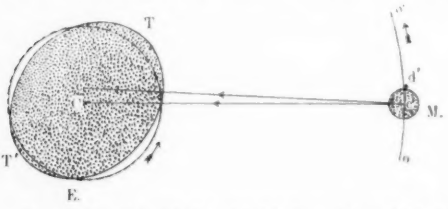
I. Saturn and His Rings, the Classical Illustration of the Laplace Ring-Theory. Drawn by E. E. Barnard.

remains to emphasize more clearly the all-important issue, before turning from the old nebular hypothesis. Laplace went a long step beyond Newton in asserting a natural rather than a miraculous origin for the solar system; but he fell a long step short of any clear conception of what a process of evolution meant when he treated the development, the growth, of world-systems as a chapter of history belonging to a period indefinitely remote from the present. To him "cosmogony," *κόσμος γένειν*, was literally, the *begetting*, in a given epoch in the far-off past, of the ideally perfect *cosmos*, the world-system with its mathematically rigid mechanics, its eternal circle of periodic changes,—the world-system of his *Mécanique Cèleste*. Doubtless he must have felt that rigid mechanics were but one side of the science of the stars, but such intuitions found almost no expression in his lifework. Had cosmogony meant to Laplace what it must mean to us, he, and not Charles Darwin, astronomy, and not biology, would first have preached the gospel of evolution, the gospel of which Laplace was the first great prophet.

The difference in the point of view becomes strikingly clear the instant we turn to the work of George Darwin. He did not address himself abruptly to the question, "What possible process in the remote past would account for the world systems as they now are?" but instead he undertook to discover what processes now going on meant continuous evolutionary change, at the very present moment, in the character and relations of the heavenly bodies; and what would be the history of change as the working of present processes was traced back without break into the indefinitely distant past. Our own solar system, as the part of the of the heavens of which there was the most detailed knowledge, seemed the logical field of research; and yet it might have seemed an almost hopeless task to make any radically important addition to Laplace's exhaustive researches on planetary mechanics. But there was one fundamental assumption in Laplace's work that, though justified as a practical means to the end he had in view, was to be qualified by later more detailed analysis. He had always assumed in his mathematical treatment of the planetary motions that the bodies in the solar system were either perfect unchanging spheres or, when he did take them as flattened at the poles, exact unchanging spheroids. And it was from this basis that he reached his grand mathematical generalization, that so far as just the mere mutual attractions of planets, satellites and Sun were concerned the solar system was practically stable for eternity. He of course knew that other influences might shake

this stability, but he never took into account the fact, which he yet to some extent realized, that the very mutual attractions of the bodies in the solar system changed the individual shapes of those bodies from moment to moment, that these changes of bodily form meant new phases of mutual attractions, and so the very fact of mutual gravitation that taken on one side meant eternal stability, taken on the other side meant perpetual change. And dissolving the opposition between these two sides by giving each its function, the new truth is,—relative, evolutionary, instead of ideal, stability. George Darwin, as a mathematical physicist interested primarily not so much in purely astronomical problems as in the physics of the earth, was brought face to face with the fact that the mutual gravitation of the Earth and Moon and Sun means, not only that these attract each other as wholes, but also that the Earth, and therefore also the Moon and, to some degree, the Sun constantly change their bodily forms so as to change concontinually the character of their mutual attractions. In short, the tides raised in the Earth, Moon, and Sun by mutual gravitation would constantly change the character of the relative motions of those bodies. Oceanic tides would have this general effect, but it was the more profound effects of bodily tides, tidal distortion due to the fact of some degree of viscosity in the whole mass, that were made the subject of research. Taking the Earth-Moon system for an example, the general principles developed may be briefly outlined.

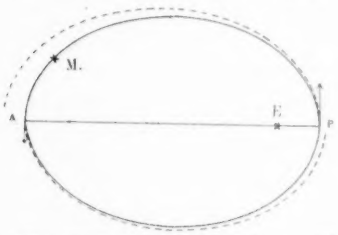
The Moon constantly tends to raise a tidal bulge on each of the two opposite sides of the Earth that are directly in the line that passes through the Moon's centre and the Earth's centre,—a bulge on the side nearer the Moon due to the attraction being greater on the part of the Earth nearest the Moon than on the more central part; a bulge on the side away from the Moon due to the attraction being greater on the central part than on




II. E, Earth with its tidal bulges, T and T′; M, Moon, as tide-raising body (relative size exaggerated). E rotates on its axis, C, faster than M moves along its orbit, (o — o′), and thus T is constantly carried ahead of M, while T′ falls behind. T, because the nearer, affects M more than T′ does. Therefore M is attracted toward E in the direction (c′ — c), a combination of the attraction (c′ — C)—which E would have for M if there were no T and T′—and (C — c), or its equivalent (c′ — d′), the attraction due to T. (c′ — d′) thus represents the "hurrying-along" of M in its path (o — o′) by T.

the part farthest away from the Moon. But though gravitation is an instantaneous force, the Earth is not an ideal perfectly elastic solid, but a fluid of great viscosity, and there is therefore frictional resistance to the motion of its particles over each other, and this resistance is practically a force operating against the Moon's attractive force. If the Moon remained constantly directly over one given point on the Earth's surface, these two forces would act in exactly opposite directions and as a result there would be two permanent tidal bulges on respective exactly opposite sides of the Earth, and frictional resistance would simply prevent these bulges from being as high as the Moon's attraction would tend to make them. But the Earth rotates on its axis from west to east many times faster than the Moon revolves from west to east around the Earth. Therefore the tidal bulge that the Moon tends to raise at the point on the Earth directly beneath the Moon at a given instant of time is delayed by the counter force of frictional resistance until the given point has been carried by the swift rotation of the Earth, somewhat ahead, to the east, of the Moon's position; and so the tidal bulge on the side of the Earth toward the Moon always keeps a little ahead, a little to the east, of the Moon,—that is, of the place in whose zenith the Moon is at any instant of time; and the other bulge, exactly a half circle away, always keeping a little ahead, east, of the place directly under which, in whose nadir, the Moon is at any instant, will always be a little to the west of, behind, the Moon's position. Then since the moon in its revolution round the Earth is constantly moving toward the east, the tidal bulge to the east of the Moon will constantly tend to draw the Moon along faster in her path, while the other tidal bulge, to the west of the Moon, will tend to hold her back. But the bulge to the east is on the side of the Earth that is nearer to the Moon, and therefore its effect in accelerating the Moon's orbital motion is greater than the effect of the other bulge in retarding her motion. Further, in accord with the law that action and reaction are equal and opposite in direction, and that the amount of motion, the moment of momentum, in a system of bodies remains constant, while the Moon's motion is being accelerated by the tides of the Earth, the Moon reacts by holding back on the Earth's tidal bulge, and this holding back slows up the Earth's rotation and generates heat in the Earth through the resistance to the motion of the tidal bulges from east to west in opposition to the Earth's rotation from west to east. Thus tidal friction on the one hand slows the earth's rotation, constantly increases the length of

the day, and, on the other hand, tends to increase the speed of the Moon's orbital motion. What will be the effect on the Moon's orbit of accelerating the Moon's motion? The orbit is an ellipse with the Earth approximately in one of the foci, and thus the point at which the Moon is nearest the Earth, perigee, and the point at which she is farthest from the Earth, apogee, are the two ends of the major axis of the orbit. Consider just these two opposite points, for simplicity's sake. It can be shown that the acceleration of the Moon at perigee will make her swing out farther from the Earth when she reaches apogee, and so also that acceleration at apogee will make her swing out farther when she reaches perigee. But the result is not simply enlargement of the orbit. It can be shown that acceleration due to tidal friction varies inversely as the seventh power of the distance of the tide-raising body. For instance, if the tide-raising body were brought to one-fourth its original distance the accelerating force would be increased $4 \times 4 \times 4 \times 4 \times 4 \times 4 \times 4 = 16{,}384$ times, theoretically—practically the difference would be a good deal less. Obviously, then, the swinging out at apogee, due to acceleration at perigee, would greatly exceed the swinging out at perigee, due to acceleration at apogee; and thus the near point of the orbit would get relatively nearer and the far point relatively farther away, and the focus the Earth occupied would get constantly farther, proportionately, from the orbit's centre. Acceleration would not only lengthen the major axis of the orbit, but also constantly make it more eccentric. The fundamental effects of Tidal Friction are thus:—Slowing of the rotation of the tide-bearing body, and increase of the eccentricity and length of major axis of the orbit of the tide-raising body. There are other effects in special cases that are too complicated to be outlined here. Furthermore, in a case exactly the converse of the one we have had before us, in a case of the Moon revolving faster than the Earth rotates and causing the tides to prime instead of lag, all the principal




III. Ellipse (exaggerated eccentricity) representing Moon's orbit about E, the Earth, in one of the foci. Tidal action, tending to drive the Moon away from the Earth, will be much greater at P on the Moon's orbit than at A. Hence the swinging-out at A, due to tidal action at P, will be much greater than the swinging-out at P, due to tidal action at A. A thus moves away from E much faster than P does, and so the focus E gets constantly more and more "out of centre,"—the ellipse grows more eccentric as well as bigger.

effects would be reversed. It remains to note in passing that only one side of the Tidal Friction problem has been referred to in this paragraph; the Earth is a tide-raising body with reference to the Moon, as well as the Moon a tide-raising body with reference to the Earth. This fact enormously complicates the mathematics of the problem, but, without, in general, invalidating the results that have been outlined.

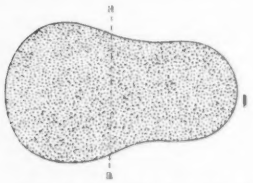
Darwin took the Earth-Moon System as the special subject of his investigations for the obvious reason that the oceanic tides raised on the Earth by the Moon had been the immediate source of all our knowledge of tidal action. And though the tides mainly considered in his work were internal, bodily tides, of which there is practically no observable trace in the present Earth, he readily proved that the oceanic tides produced results of the same general character, differing only in minor details. It is a strange fact that nearly two centuries should have gone by after Newton discovered the cause of the oceanic tides, before anyone clearly stated the principle of Tidal Friction. On the basis of the general theory of Tidal Friction, just outlined, Darwin traced the Earth-Moon System back from the present to the distant period when the two bodies first had separate existence, and by rigorously mathematical methods constructed a history that, though extremely uncertain in its minor details, was probable to the degree of practical certainty in its general features. And looking the other way he projected the process of change into the future to complete the cycle of Tidal Friction development. At the beginning of that cycle,—Moon and Earth both in rapid rotation, and the Moon revolving close to the Earth's surface in a month far shorter than the present; then a slowing of the Moon's rotation period until reduced to the condition it is still in,—identity with the revolution period, the month; a slowing of the Earth's rotation period toward the length of the day of the present; and, with these changes in rotation, the winding off of the Moon from the Earth in a close-coiled spiral, the orbit growing ever larger, and also at first rapidly increasing its eccentricity to a maximum and then slowly reducing that maximum toward the existing degree. Also progressive changes in the inclination of the lunar orbit and equator and of the Earth's axis. This for the past. For the future:—Still further reduction of the Earth's speed of rotation till the future day become identical with the future month; still further winding-off of the Moon and reduction of her orbit's eccentricity, until a maximum distance and nearly circular orbit is reached; and then the slow beginning of the reversal of the

story, and somewhere in the unfathomable to-be, the meeting of the Earth and Moon to end their existence as separate members of a system. This history has been several times presented in clear untechnical form in recent works on general astronomy, so it need not be carried into further detail here. So far as the time-estimates are concerned, too great uncertainties on the early physical condition of the Earth, and too great mathematical difficulties, are involved to make such estimates trustworthy within other than extremely wide limits. It must suffice for the present that we know the whole process to have been exceedingly slow, involving tens of millions of years. The fact that the process is too slow at the present time to be directly observable with any means we possess, does not give a safe basis on which to work, for we have to consider that the potency of Tidal Friction varies, theoretically, as the seventh power of the distance of the tide-raising body; and therefore, even allowing for practical great reduction of this ratio, the changes considered may have gone on with vastly greater rapidity in the remote past when Moon and Earth were near together. The one important result thus far derived from the attempt to estimate the time-duration of the process has been to bring the estimates of the age of the Earth on the astronomical side far more into accord with those made, on fairly definite data, by geology. The age of the solar system based upon theories regarding the past duration of the heat of the Sun, the basis upon which the astronomical estimates have for the most part stood, falls far short of the time that geology justly demands for the history of the Earth. The Tidal Friction work, as a clearly defined process, therefore helps to indicate that we have yet only a partial account of the development of the Sun's heat. The physics of intensely heated bodies is still highly speculative.

In the closing part of his work Darwin came abruptly against a fundamental difficulty in trying to bridge the gap between the beginning of the Tidal Friction history of the Earth-Moon System and the earlier historical period with which the "nebular hypothesis" had dealt. How did the Moon come to have existence as a mass separate from the Earth? How did the Earth-Moon Mass become the Earth-Moon System? The speculative answer of Laplace, that the semi-fluid Earth-Moon Mass had shed an equatorial ring that later broke and condensed into the Moon, presented insurmountable difficulties before the problem of the beginning of tidal action, and in fact had its probability reduced to a minimum by the mathematics of the Tidal Friction theory. In a foot-note to his closing paper on that theory in the

Philosophical Transactions of the Royal Society for 1881, Darwin suggested that he had begun to entertain grave doubts on the correctness of the old speculation, and hoped to bring the doubt to a definite result. In 1887 he gave to the Royal Society a most remarkable mathematical discussion of the method in which two spheroids, revolving about their common centre of gravity, close to and approaching each other, would finally blend into a single mass. Reverse this process and it would give a possible method in which a rotating mass might become a system of two masses. He approached the problem from the basis of the certainty that systems of two bodies, such for instance as planet and satellite, actually did exist, and the end he had in view was the testing of what was involved in the assumption, that had merely been taken for granted, that the two masses had been originally one. This was the scientific logic of his approach from what might seem at first sight to be the tail end of the difficulty. But at the very same time, though the publication of the results came a year earlier than Darwin's, the great French mathematician, Poincaré, altogether independently and with the same general idea in mind, attacked the problem from the opposite end,—started with the single rotating mass and undertook to discover whether or not it could become two masses, and, if so, how. The two men working from opposite standpoints reached results that were essentially the same and therefore mutually confirmatory beyond expectation. There were other figures of equilibrium, for rotating fluid masses, that implied less ideal conditions and were practically far more probable than the spheriods of Laplace; and when the figure of a rotating mass became one of unstable equilibrium, it was improbable that the lesser portion tending to separate from the greater would have the form of an equatorial ring. Jacobi had shown that a rotating ellipsoid may become elongated under the influence of rapid rotation, the long axis of the mass being the long axis of the equator of the new ellipsoid and perpendicular to the axis of rotation. Lord Kelvin and others had seen that as the Jacobian ellipsoid elongated more and more, under the influence of continued rotation, it must finally cease to be a figure of stable equilibrium, and then it seemed probable that it would somehow part into two unequal masses. But the difficulty was that mathematics had never bridged the gap between, on the one hand, the elongated Jacobian ellipsoid that was perfectly stable, and, on the other hand, the two separate masses in the most primitive condition in which they would be in stable relation to each other. The critical

region between was purely speculative ground. Darwin and Poincaré both found that when the Jacobian ellipsoid became so elongated as to reach the limit of its stability it did not abruptly rupture but passed into a new figure of equilibrium, the apioid,—named from the Greek ἄπιον, a pear, and εἶδος form,—an egg-shaped figure becoming, by the development of a furrow all around it between its lesser and its greater ends, approximately pear-shaped. By the deepening of the furrow and the further elongating of the mass the apioid gradually became dumb-bell-shaped, the axis of rotation of course continuing as before perpendicular to the long axis. Then finally the neck of the dumb-bell would rupture and the two unequal bulbs would continue to revolve, though as a system, about their common centre of gravity, and each would have a rotation of its own in the same direction as the original rotation of the single mass. The very existence of the apioid and the dumb-bell with unequal,—or for that matter even equal,—bulbs was a new light on the physics of rotating fluid masses. But the final difficulty was the practical application of the results to the field both scientists had in view, the solar system. Darwin's numerical interpretations made the greater of the two masses formed never more than thirty times the size of the lesser, and Poincaré found even far less difference between the two. Yet the Earth is eighty times the mass of the Moon, though the Moon is the largest satellite, in proportion to its planet, that we know; and as to the whole solar system,—the Sun is seven hundred fifty times the mass of all the planets and satellites combined. There was but one significant ground for hope: both investigators had considered relatively homogeneous or only slightly heterogeneous rotating fluid-masses; but both had found reason to infer that if the original mass were in a high degree heterogeneous the companion masses resulting from the "fission" process might be of widely different orders of size. The mathematical difficulties of a proof of this inference seemed baffling; and ocular evidence was altogether wanting that any mass in the whole solar system had ever parted into two masses of anything like comparable size,—the Earth-Moon System had a ray of possibility in it, but it was evidence really a good deal poorer than the Saturn rings were for the old ring-theory of Laplace.



IV. Poincaré's Apioid, the pear-form assumed by a rotating mass under long-continued rotation. A figure of rotation unknown to Laplace.

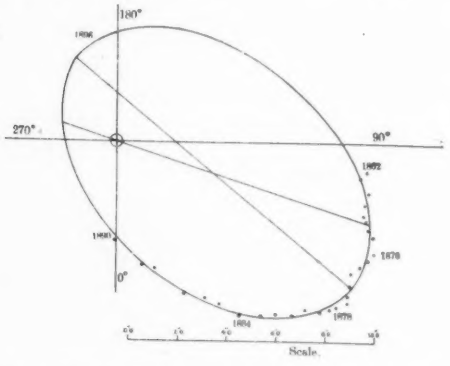
So there seemed no alternative but to admit that the tremendously difficult mathematical work had failed of other than the most purely ideal results. There was a suggestion of the lines future investigation might take; and there was a grave doubt cast on one important assumption in the time-honored "cosmogony" of a century past.

Several other names besides Darwin and Poincaré are to be taken account of in connection with the beginnings of the new evolutionary cosmogony. The work of Lord Kelvin, on the heat of the Sun and the rigidity of the Earth was of the highest importance to Darwin both in his investigation of Tidal Friction and in his more speculative research on the primitive Earth-Moon Mass. The great Helmholtz made valuable contributions to the general problem through his work on the Sun's heat. And back in 1863 Dr. T. F. Mayer developed some interesting foreshadowings of the Darwinian tidal theory.

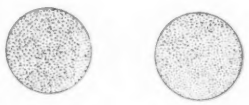
But the papers that Darwin gave to the Royal Society between 1878 and 1882 on the Tidal Friction History of the Earth-Moon System were of far more vital significance than all the other attempts made, until a few years ago, to definitely outline a process of evolution, in the province of astronomy. This Darwin accomplished for our own planet and her satellite, and so far successfully that none of the fundamental features of his results seem likely to be ever called into question. Yet the Earth and Moon are a trifling fraction of the field astronomy has before it, and indeed a minor factor in even just the solar system. That tidal friction would have some effect in any system of heavenly bodies was clear; but could it be said to have any marked importance beyond the limits of this one demonstrable case of the planet Earth and her companion? The question could not be answered. Nowhere else did there seem to be evidence by any means conclusive that tidal friction had ever played any part at all. The satellite systems of two or three other planets presented significant peculiarities, but nothing that was reasonably definite. The prime difficulty was that it was doubtful that tidal friction could count for much unless the tide-raising and the tide-bearing bodies were of something like comparable size; for where the two bodies in a system were of widely different orders of size, it was difficult to prove that either could raise tides in the other of sufficient magnitude to materially effect the motions of the system. And all the planets save the Earth were vastly larger than their satellites, and the Sun was over seven hundred and fifty times the mass of all the other planets and satellites put to-

gether. Darwin had struck the key-note of a truly scientific method of approaching the problem of the development of the heavenly bodies; and he had cast a lasting doubt over the tacit assumption of the centuries that the planetary motions were one thing in the universe so ideally fixed that it was a hopeless task to try to find in them a process of growth, of evolutionary change. And still, cosmogony as a real science was only in its beginnings so long as everything but the modern history of our little Earth and Moon remained in the haze of vague speculation. Astronomers had indulged in speculative cosmogony from time immemorial; and mathematical physicists had finally come to give the general subject a goodly share of their attention, and had begun to shape its future along legitimate scientific lines. The way was open for the critical step to be taken that should clearly launch the science of astronomy, with its inheritance of rigid ideals, into the stream of evolutionary thought.

In the *Naturwissenschaftliche Rundschau*, for June 10th, 1893, Berberich, the illustrious computer at the Royal Astronomical Observatory of Berlin, wrote: "The work of Mr. See (on the evolution of double star systems) has in it greater promise than all the other hypotheses and theories on cosmogony taken together." All previous discussion of the development of the heavenly bodies had been focussed upon the solar system as the



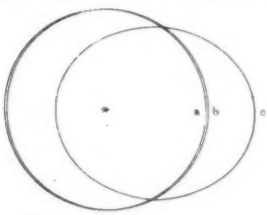

VI. Orbit of Sirius, the great "dog-star." Period of Revolution:—about 52 years. Greater star 10,000 times as bright as lesser, but only 2¼ times as large; and 2¼ times the mass of our Sun.



V. Relative masses (as forty-nine to fifty-one) of the two members of the double-star system $\alpha$ Centauri, the nearest of the fixed stars. Larger mass about equals our Sun. A fairly representative double-star. In the solar system the greatest body, the Sun, is 1048 times the mass of the greatest of the planets.

traditional familiar example of a system of bodies moving under the direction of their mutual gravitation. But when astronomy looks beyond the narrow limits of the solar system into the

great universe of fixed stars, it looks in vain for another system like our own, and finds a countless host of systems of a wholly different type. The telescope and the spectroscope together reveal the fact that probably half of all the fixed stars we see are not each a single great luminous sun, but each a pair of suns, of comparable brightness, both revolving about their common centre of gravity. Many of the other fixed stars may be single suns attended, like our own, by a retinue of tiny planets and their satellites, but any assertion that this is true rests on the outcome of an extremely indefinite problem in the mathematics of probability. When, therefore, we put aside the peculiar value that attaches to the solar system as including the planet Earth, we come to realize that, so far as our present actual knowledge is concerned, the solar system-type, the double-star, presents a far more frequent method of star-development. This fact attracted the attention of T. J. J. See as early as '87 or '88, while he was a student at the University of Missouri, and interested him in undertaking to review the recorded observations and mathematical discussions of double-stars. His study immediately brought to his notice a peculiarity in the relative motions of the two members of the double-star system no less striking than the fact of the comparable size of those members. The eight principal planets of the solar system and their satellites move in orbits that are ellipses of never more than a slight degree of eccentricity; in other words, orbits that are almost circular. But in the case of the general average of double-stars the two members of the system describe orbits around its centre of gravity that are ellipses of a high degree of eccentricity, rarely even approximating the circle. So remarkable a feature must find its explanation in some factor in the mutual attractions of the two bodies composing the system,—some factor that would be of comparatively inconspicuous importance in the solar system. There were but two other practical alternatives to this conclusion:—either the disturbing influence of bodies outside each double-star system had compelled the highly eccentric orbits, though there was not the slightest evidence that this came within the range of even doubtful probability; or else, the way in which each double star




a = Circles.
b = Average planetary orbit.
c = Average double-star orbit.

VII. To show the great contrast between the average eccentricity of the orbit of a double-star member and the average eccentricity of a planet orbit in the solar system.

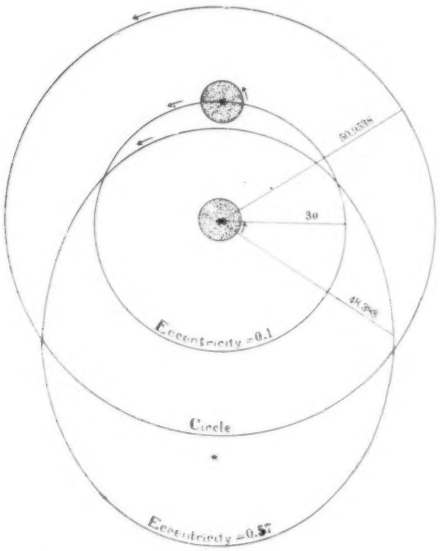
first came into existence as a system created the high eccentricity,—and this scarcely lay within the possibilities of any rational speculation. The question stood: Would two suns of comparable size and revolving near together around their common centre of gravity attract each other in the same way as a great sun and one or more tiny planets together forming a solar system? There was one inevitable great point of difference between the two cases,—that the bodily tides raised by mutual gravitation in the members of the double-star would be vastly greater proportionately; for the tides raised on the Sun by a planet are practically nothing, and the tides raised on a planet by the Sun are comparatively small because the distance from the Sun to the near side of the planet is an insignificant fraction less than the distance from the Sun to the far side, and on this difference the size of the solar tides depends. See was familiar with the principle long since demonstrated for the planetary motions that continued acceleration, depending on a law of an inverse power of distance, of a body moving in an even slightly eccentric orbit would tend to render the orbit more eccentric. Here, then, in the double-star systems were too coincident facts unique to those systems:—high orbital eccentricity and great bodily tides,—the first fact based on observation; the second on no assumptions more improbable than the validity of the law of gravitation in remote space, and the viscosity and imperfect rigidity of luminous solids or semi-fluids. The hypothesis presented itself that these bodily tides somehow so affected the mutual attraction of the bodies as to produce continued mutual acceleration of their orbital motions, although their attraction on each other as wholes, disregarding all tidal distortion of each mass, would simply maintain the orbital motion without ever tending to change its average rate. And from acceleration highly eccentric orbits would inevitably result. A rough calculation soon proved that when the tides lagged, that is, when the attracting bodies rotated on their axes somewhat faster than they revolved in their orbits, the hypothesis would hold; and there was sound physical reason for believing that in any system, during at least some large period of its cooling from the gaseous to the solid condition, rotation would be faster than revolution. Thus the conviction came that the high eccentricity of the double-star orbits was evidence of a process of evolutionary change constantly going on in them, and that the obvious potent factor in that process was Tidal Friction: the eccentricity was the ear-mark of Tidal Friction.

George Darwin had started from the observed fact of the existence of lunar tides, and reasoned to the tidal friction process as a necessary consequence. Then he had found in the Earth-Moon System confirmatory evidence, but had failed to find it beyond. See had started from the known fact of the necessary existence of tides in the bodies of a system,—this constituting the casual side of the problem—and the observed resultant side, the high eccentricity of the double star orbits; and then discovered that these two sides functioned as cause and result in a process of tidal frictional evolution. See reached this conclusion a year and a hall before he learned that Darwin had ten years before proved mathematically that the eccentricity of an orbit could be a result in the tidal friction process and that the Earth-Moon System had served as one isolated application of the mathematical theory. He had merely gotten a general notion of the principle of tidal friction without any suggestion of its bearing on orbit *eccentricities* from a popular review of Darwin's papers. But rediscovery of the principle as operating in the multitude of double-star systems was destined to raise it to the unquestioned importance of *a fundamental law of cosmic development*, an importance that it could not be accorded in its earlier far more limited practical application. After the first rough sketch of the double star work had been written See spent several years on the investigation at the University of Berlin and presented the results as an inaugural dissertation for the doctorate of philosophy, in December, 1892. This thesis, written in German and entitled "Die Entwickelung der Doppelstern-Systeme," "The Evolution of Double-Star Systems," was a rigorously mathematical discussion, based in large part on George Darwin's work, but going a long ways beyond that work in the definite lines laid down for the development of a practical science of cosmogony whose scope should be as broad as the whole field of observational astronomy.

The method of approach to the double-star problem was determined by conditions somewhat different from those obtaining in the case of the Earth-Moon problem of Darwin. No single double-star system was thoroughly enough understood to furnish practical data that would lead to safe general conclusions. The alternative was to assume an ideal system that should embody in its characters the general features that the observation of numerous double stars had safely determined and then to make a sufficiently wide allowance for inexactness in the assumptions to reduce the elements of improbability in the final results to a minimum. So the foundation for the whole process of research was

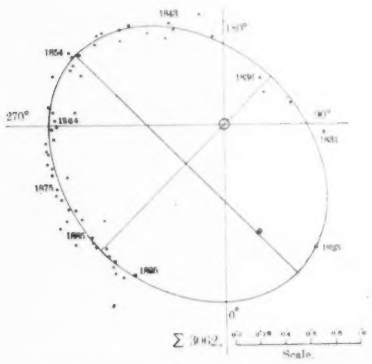
laid by the discussion of the simplest practical ideal system. And this was taken to be a system composed of two great suns, larger and far less dense than our own, identically like each other in size, shape and constitution, both spheroidal in form, revolving about their common center of gravity in slightly eccentric orbits, and rotating somewhat faster than they revolved, both in the same direction and with the same speed. In a real system there is, of course, never this identity of character in the two components, but later investigation of more complex ideal systems, approaching more and more closely the actual conditions, revealed the fact that the results derived in the first simple case would require to be modified in various details but would hold substantially true in all broad general outlines. The full statement of these special cases is to be presented in an extended work on "The Evolution of the Stellar Systems," the first volume of which is now in press, but in the preliminary dissertation published in Berlin in '92 See confined himself to working out in full the primary simple case as the crucial test of the whole problem and of the method of its solution. The frame-work there constructed of the tidal history of a double star did not differ in general theory from Darwin's results for Earth-Moon System, though the practical application had a fuller significance. When the two members of the double star first come into existence as separate components of a system they together have a greater amount of kinetic energy than they will have at any later period of their history and this kinetic energy will be manifest partly as molecular motion, heat and its derivatives,—the bodies being in a more or less gaseous, fluid or semi-solid condition,—and partly as molar motion, the condensation of cooling matter under the influence of gravitation and the derived momentum of revolution of the two bodies about the center of gravity of the system and of rotation of each upon its own axis. The progressive cooling of the bodies continues to develop rotation, and tidal friction continually transforms energy of rotation into heat that is dissipated into space, and finally the bodies become dark and cold and practically all the kinetic energy in the system except a part of the momentum of revolution is transformed into mere energy of position, potential energy, and we have two dark, cold, solid masses, ellipsoidal in form, slowly revolving at a vast distance from each other, about the system's center of gravity, in orbits that are perfect circles, and always presenting the same face, respectively. toward each other,—that is, rotating in the same period that they revolve in, just as if they were immovably fixed on either end of a bar

that was balanced and rotating on some point between its ends. Condensation of each body at first constantly increases its speed of rotation toward a maximum, and then ceases to augment or to maintain rotation as the body approaches the practically solid condition. The tidal friction history has three definite aspects:—the reduction of the speed of rotation of both system-members, with the transforming of rotational energy into heat to be dissipated into space; the continual winding off of the two from the system's center of gravity until they reach a certain maximum distance from each other; and—this of special import to us here—at first a slight decrease in the eccentricity of the orbits, then a long slow process of increase until a high maximum eccentricity is attained when the bodies are almost at the greatest mean distance apart they are destined to reach, and then a sudden rapid decrease of eccentricity till the orbits become practically circles when the mean distance of the bodies has reached its maximum. This final condition of the system would close the history and the system circle on unchanged through eternity, were it not that, in the first place, there never could be the ideally balanced conditions assumed by the mathematical treatment of the problem; and, in the second place, even when in any case the ideal balance of conditions seemed practically fulfilled, there must inevitably be some however slight outside disturbing influence,—since no system is alone in infinite space,—to break the equilibrium. So it can be shown that when the stability of this final

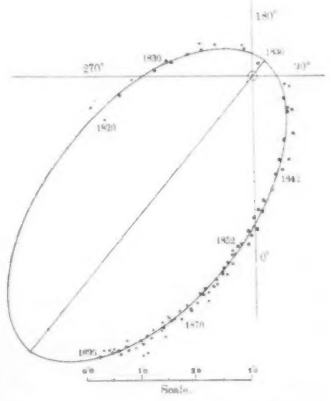



VIII. Ideal case to show increasing size, and changes in eccentricity, of a double-star orbit under the influence of Tidal Friction. Early stage:—Ec. 0.1; distance of stars from each other 30 times the distance of the Earth from the Sun. Later stage:—Ec. 0.57, the maxium; distance 49.388. Latest stage, before system begins to reverse its evolution:—Ec. 0.000; distance 50 astronomical units.

stage is broken the action begins to reverse, partly by reversed tidal frictional influence, partly through the friction of the dispersed meteoric matter in space retarding the motions in the system; and the stars wind back toward and finally fall into each other and the existence of the double system ends. The numerical results showed that the maximum eccentricity developed by tidal friction in a case where the assumed conditions fall far within rather than beyond the range of probability was high enough to make it certain that that process could have developed the observed high eccentricities in the double-star orbits. A table of all these orbits that had been determined with certainty showed an average eccentricity *twelve* times as great as the average eccentricity of the principal orbits in the solar system, and the conclu-




IX. Orbit of the double star known as Σ 3062. A fine example of an orbit of average eccentricity. Period of Revolution:—about 105 years.




γ Virginis=Σ 1670.

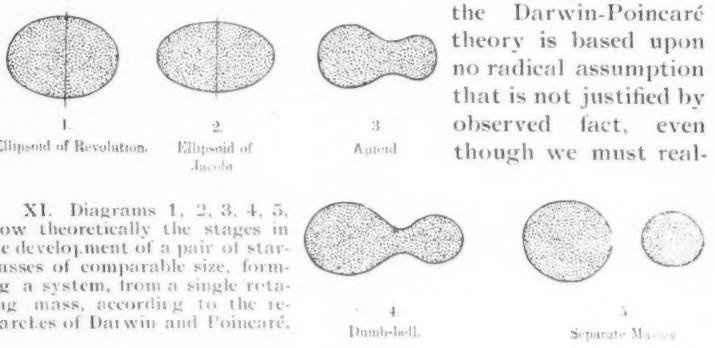
X. γ Virginis, one of the most eccentric double-star orbits known. Each of the two stars has an orbit of this form about the common centre of gravity of the system, but in the study of the system it is simpler, and does not change the results, to regard the larger star as the centre of attraction (shown as small circle) with the lesser star revolving about it. The dots, some of which are dated, represent the successive positions of the companion star as observed through a long series of years. The ellipse is the apparent path (orbit) determined by plotting out these observations. Period of Revolution:—about 194 years.

sion was irresistable when this was coupled with the fact that the comparable size of the system-members in the double stars meant far greater tidal action than in the solar system. The almost circular orbits in some double-stars were in no way contradictory of the tidal friction principle, since they might represent either an early or far advanced stage of the process; but the highly excentric orbits of others could find an explanation in

no other conceivable process. For example, such a case as that of $\gamma$ Virginis, an eccentricity of nine-tenths, the orbit so elongated that either focus is nine-tenths of the distance away from the orbit's centre to the end of the major axis and in each revolution periodthe two stars are nineteen times as far apart when farthest from each other as when nearest together.

Thoughout the investigation the question presents itself:—what certainty is there that the two members of a double star are of comparable mass? Even in the greatest telescope the nearest fixed stars are only points of light with no measurable surface. In a few cases it has been possible to determine by their relative motions that the two members of a double-star system were certainly not more than slightly unequal in mass; in the remaining cases the relative brightness of the two members has been taken as an indication, and the averaging of a tremendous number of comparisons reduce the uncertainties in the method to a minimum. It has thus been found that we may safely conclude that the greater of the components is generally three or four times the lesser in mass. Only in a few isolated instances is there any wide departure from this degree of difference in magnitude. But at the same time that this result confirms the tidal friction process for the history of the double-star systems, it invalidates completely the assumption that the beginnings of such systems were similar to the beginnings that have so long been assumed for the members of the solar system. Laplace himself realized and stated in a single sentence in the nebular hypothesis that the double stars were an exception to the theory of ring formation. It is a physical impossibillty, past all shadow of doubt, that the lesser member in a double star should have separated from the greater as an equatorial ring of their original rotating nebula. The work of Darwin and Poincaré on rotating masses immediately flashes across the mind. See perceived that the clear application of their theoretical results was to be made where they had not thought of looking, far beyond the solar system that had discouraged their hopes, in the systems among the fixed stars. Then turning back some almost forgotten pages of the earlier astronomy See pointed out some remarkable evidence for the Darwin-Poincaré work in the monumental labors of Sir John Herschel on nebulæ. Herschel's great catalogue of 5079 nebulæ stated that over 300 out of the minority whose form was determinable were "double," and many of his accurate drawings of these double nebulæ presented figures clearly approaching the dumb-bell figures of equilibrium, in

various phases of their development, as mathematically constructed by Darwin and Poincaré. The startling probability rises before us that here in these double nebulæ, by far the most abundant of the definitely formed nebulæ in the heavens, we have nascent double stars. That a single great nebula is the beginning of each double star system is certain; for it is clearly established that no other hypothesis of the origin of these systems is physically tenable. And that the original mass is set in rotation by condensation of its particles toward the mass-center by reason of their own attraction and that the rotation finally breaks the equilibrium of the single mass and parts it into two or more masses,—all this rests upon the clearest results of the best physics of today. Furthermore, the method of the breaking outlined in the Darwin-Poincaré theory is based upon no radical assumption that is not justified by observed fact, even though we must real-




XI. Diagrams 1, 2, 3, 4, 5, show theoretically the stages in the development of a pair of star-masses of comparable size, forming a system, from a single rotating mass, according to the researches of Darwin and Poincaré.

ize that the actual process can never be observed through any means we now possess. Deeper study of double nebulæ by photography and the spectroscope may reveal a different meaning in them than that suggested, but all our present knowledge lends force to the belief that they give us definite data for the investigation of nascent star systems.

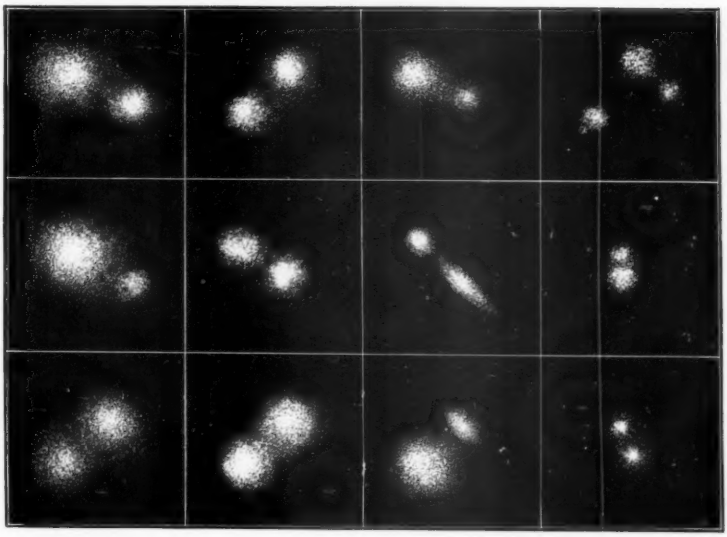
The closing paragraphs of See's Berlin dissertation are devoted to outlining the bearing of the double-star work upon the problems of evolution in our own solar system, and as we read these pages we see before us a striking illustration of a great law of scientific progress. Science always first approaches, in attempting to solve a problem, the fields that are most familiar to her experience but in which her knowledge of complex detail is at once a stimulus and an obstacle to thought. Then, inspired by the foreshadowings of truth, but baffled in her attempt to grasp a definite statement of the truth, she turns to the unfamiliar fields where the very limitations of her knowledge, freeing her

from bewildering detail, make possible a simplicity of method that clears and defines her conceptions, and reacting throws new light upon the old familiar subject-matter. So cosmogony first studied the well-trodden field of the solar system, where a wealth of detailed knowledge, as also a feeling of human self-interest, inspired research; and now has turned to the far off systems among the fixed stars to find in the very simplicity of our knowledge of them, with the absence of irrevelant detail, the means of clearing and defining the conceptions of processes whose nature earlier study only foreshadowed. And now looking back upon our own solar system from the standpoint of the fixed stars, new meaning dawns on the problem of its development. Since Tidal Friction is a foundation principle in all the other known systems in space it must be of unquestionable importance in constantly modifying planetary motions; though at the same time we find in its action in the double stars conclusive evidence that it has had far less radical influence in the solar system than in them. We thus at once come to realize that Tidal Friction is as universal as gravitation, but that the degree of its efficiency as a cause of change varies according to a definite law of the distance apart and relative size of the bodies whose mutual motions it affects. Further, if the formation of the myriads of double-star systems from nebulæ wholly contradicts the ring theory of the nebular hypothesis, why is it not highly probable that the solar system represents simply a special case of the same general process by which a nebula becomes a double star? Especially since there is clear mathematical ground for believing that though a relatively homogeneous mother-mass would part into two comparable masses, a very heterogeneous mother-mass might become a great sun attended by tiny planets. The old ring-theory rests on almost purely sepeculative assumptions, for observational evidence that it is practically possible is wholly lacking. There are supposed ring nebulæ in space but their exact character is in the highest degree dubious—practically there is nothing approaching exactness in our knowledge of them. The belt of countless telescopic planets in between the orbits of Mars and Jupiter have been often cited as an example of a ring that broke into many fragments instead of condensing into a single planet. But it is more than doubtful, though barely probable, that this was one case of ring formation, and perhaps equally likely that one or more small planetary masses thrown off by the Sun after the formation of Jupiter were torn to pieces by the tidal action of Jupiter, the greatest of all the planets, and the many fragments

became the irregular and complicated group of asteroids just inside the Jovian orbit. Finally the rings of Saturn seem to be one plausable confirmation of the ring theory, but See inclines to the belief that these could be better explained by supposing that tidal action of the planet Saturn has broken up one or more satellite masses of semi-fluid consistency and distributed the fragments into an equatorial ring. Clerk Maxwell long ago proved that the wonderful Saturn rings were a swarm of tiny meteoric satellites. George Darwin in reviewing See's work sealed the fate of the old ring theory by recalling the demonstration by Roche, some years since, that a partially solid satellite would be torn to pieces by tidal action if revolving within a certain definite limit of distance from its planet's surface. Darwin pointed to the significant fact that the rings of Saturn fell just within "Roche's limit" for that planet, and that no other satellite in the solar system did fall within that limit for its planet, nor did any planetary body approach that limit for the Sun. This leaves the Saturn rings still problematical but shakes down their validity as proofs of the ring theory. In short, the old nebular hypothesis of Laplace in all save its general outlines has been relegated to the things that are past. To those who realize how conservative always is criticism by the highest rank of scientists, the closing sentence of Darwin's immediate review of the Berlin Dissertation means much: "Mr. See must be congratulated on having written an essay of great cosmogonical interest, and although his theory may never be susceptible of exact proof, yet there is sufficient probability of his correctness of inspire us with fresh interest in the observation of double stars."

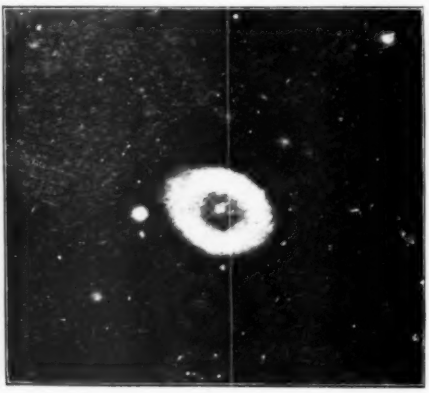
During the early part of See's work one of the most eminent of living astronomers wrote to him, in substance: "I am glad to find some one interested in studying the evolution of the heavenly bodies, but I despair of any important results ever being accomplished in these lines within the days of men now living"! And so it seemed so long as cosmogony was little more than traditional speculation on the solar system, and the hosts of the fixed stars everywhere beyond that system were regarded as a sealed mystery to the evolutionist. But the war has been carried into the enemy's country, the fixed-star heavens have yielded an unhoped-for vantage ground, and the science of cosmogony stands on the threshold of possibilities that even a daring prophet would hesitate to limit. Yet it is possible to outline with some definiteness several of the special problems that must begin to interest the rising generation of astronomers. Double stars are not

# PLATE XX.



XIII. Double Nebulæ in various regions of space, probably representing stages, actually occurring in the heavens, of the process shown ideally in Fig. XII. After the original drawings of Sir John Herschel.

XIV. The remarkable "Whirlpool" or Spiral Nebula of Lord Rosse in the constellation of the "Hunting Dogs." Photographed by Barnard.

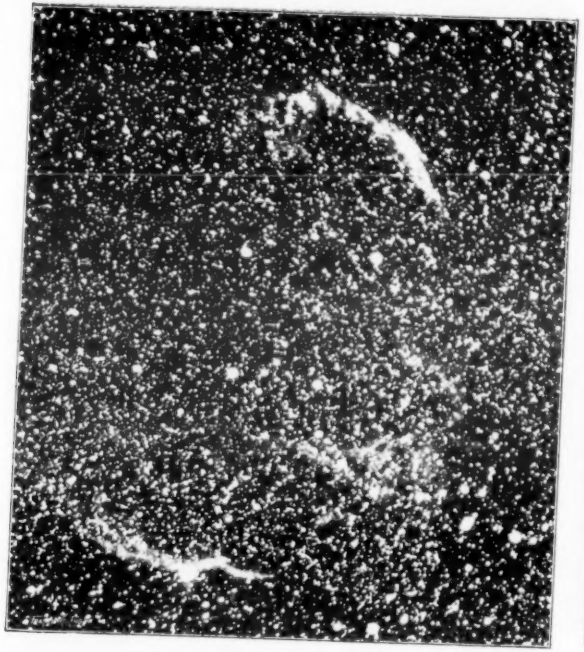


XV. The Great Ring Nebula in the constellation Lyra. Photographed by Barnard.

XVI. The Great Ringed Nebula in the constellation Andromeda. Photographed by Barnard.

XVII. Two great nebula masses in the constellation Monoceros, the one on the right discovered by Barnard. Photographed by Barnard.

# PLATE XXII.

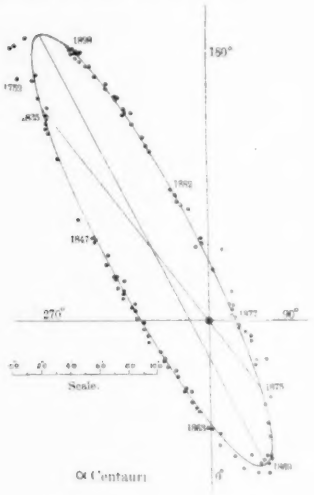


XVIII. A section of the Milky Way, with two remarkable "Wisps" of nebulosity, the lower sweeping out like eagle-wings from either side of the bright star Kappa Cygni. Photographed by Barnard.

XIX. The great Cloud Nebula, the greatest of its kind in the heavens, around the bright reddish star Antares. Several other bright stars in the constellations Ophiuchus and Scorpio are in the borders of the Cloud. The dark "lanes" running through it are especially remarkable. Photographed by Barnard.

the only systems in the fixed-star realms. The more powerful telescopes have resolved a number of the components of supposed double stars into pairs, so that we have triple and even quadruple stars, systems composed of a pair of double stars. The mother-mass has parted into two daughter-masses, and then either or each daughter-mass has itself divided. The dynamics of such a system present a tremendously complex problem. It has sometimes been asked whether or not each member in a double star, each great sun, may have its own retinue of minute planets. See answers that this is in the highest degree improbable since it is not conceivable that a planetary mass could be formed or exist in the presence of two great suns exercising complex opposing attractions. But it is probable that some, perhaps many, of the stars not known to be double are single suns with planetary systems like our own, although observational proof of this is a doubtful possibility since a planet even as great as Jupiter would be wholly invisible, to any existing telescope, at even the distance of the nearest fixed stars. Star clusters are an even far greater problem than the multiple stars but as the study of double stars has given us the key to the study of multiple stars, so the study of the latter is the most hopeful direction from which to approach the baffling complexity of the dense clusters into which the telescope resolves some of the points of light that seem to the naked eye single fixed stars. And there is still another type of system that defies all our present conceptions of celestial dynamics,—the "natural constellation," such for instance as the Pleiades; not a constellation made by human fancy, but an actual group of stars vastly remote from each other, though relatively near together so far as their distance from other stars is considered, and all moving in one and the same definite direction. The difference between such a "system" as the Pleiades and double, or even multiple, stars becomes striking enough when we consider that the Pleiades appear, to the naked eye, to occupy a large area of the heavens, but that even the double star whose members are farthest apart would have to have its orbit's length multiplied many times before it would appear to the naked eye as anything but a single star,—the nearest fixed star, $\alpha$ Centauri, which also happens to be a double star, would not appear double to unaided vision unless its components were over two hundred and fifty times as far apart as the distance from the Earth to the Sun, twelve times as far apart as they actually are. A great field of study that has scarcely been entered is that of the nebulæ, the bodies to which we must

look for light upon the beginnings of stellar systems. The distance of the nebulæ and the relative motions of their parts are the two fundamental problems and the spectroscope and the photographic camera are the astronomical instruments to which it seems most probable we must look for aid. Some suggestion of the meaning of the great class of "double nebulæ" has already been made, but the ring and the spiral nebulæ are still in the realm of the vaguest speculation, and still more so the strange irregular wisps of nebulous light that are twined around many of the stars. Finally, the great, often-repeated question rises again: Do all the stars together form a system? Conservative astronomy shrugs its shoulders at a question involving such tremendous generalization. But science has time and again been forced to grasp the hand of a problem it had many times greeted with a passing shrug. Long ago elaborate star gauging, beginning with the elder Herschel, revealed an apparent definite method in the total distribution of the stars. There extends completely round the heavens at a vast unknown distance from us the great ring-like galaxy of countless myriads of stars that we call the Milky Way. Taking this great ring as determining an equatorial plane for the whole apparent visible sphere of the heavens it is found that by far the greater part of all the stars outside the Milky Way lie within a few degrees of that general plane and that in the regions of the two poles of the celestial sphere whose "equator" is the Mikly Way, stars are few and far between but well defined nebulæ vastly more abundant than anywhere else in space. What this systematic distribution of the stars and nebulæ may mean for the existence of a great dynamic system of the heavens we cannot even pretend to guess. But the new cosmogony, developed in the spirit of classical physical astronomy, and therefore recognizing the principle of




XII. Orbit of α Centauri, the nearest of the fixed stars. Distance such that it takes about 4½ years for its light to reach the Earth. Highly eccentric. Period of Revolution:—about 81 years. Two stars of nearly equal size.

measurement as a key note in all physical science has incidentally contributed suggestions that may lead to the beginnings of a scientific solution of even this broad problem. See has worked out a theoretical method, dependent for its practical realization upon only increased exactness in the construction of the spectroscope, through which a single spectroscopic observation of a double-star may determine its distance and also test the validity of the law of gravitation in remote space; and the apparent universal distribution of double stars would thus open the possibility for the actual measurement and plotting of the real, instead of the apparent, distribution of the galaxy and fixed stars in general. Through this process of research alone may we hope some day to approximate a definite discussion of the broader dynamnic relations of the whole celestial sphere.

With all these results before us the question of their meaning for general evolutionary thought becomes a vital issue. Those who have been surfeited on the vague indefiniteness with which much of recent biology has clouded the literature of evolution, can at least feel a sense of relief, a healthful reaction, in turning from "Ids" and "Bathmogenesis" to the exact expressions of mathematical astronomy. Through the fog of morbid erudition and petty wisdom that has settled too widely over the field of controversy it is possible to make out the central problem over which biologists have been struggling since Charles Darwin first clearly stated it some tens of years ago. Brushing aside the obscurities of partisan criticism in "Lamarkism" and "Darwinism," or in Neo-Lamarkism and Neo-Darwinism, and in the various compromises that pose as reconciliations between the two, the question is simply:—the mutual relation of organism and environment in the process of evolution. The changing organisms and their changing environments have been taken to be two fixed groups of facts before us. Some have tried to show that the organism was the passive clay moulded and remoulded by the changing environment; others that the organism somehow evolved itself, and the "fittest" changes in it survived. Neither have admitted the inconsistencies in the bottom principles on which they respectively worked and neither have been consistent in their work upon those principles. But without making other comment,—further than to note in passing that Charles Darwir and a few other comparably clear minds are not classed in either of these schools,—the light that scientific cosmogony has brought to the discussion may be shortly outlined. The organism-environment

problem exists as clearly in the life-history of stars as in the province of plants and animals. A great expanded nebula somewhere in space may be taken as a physical organism and the rest of the universe as its environment. Beginning at some stage to which physical science can safely go back, trace the life-history as far as you will. The nebula condenses, its particles move towards its centre of mass. But it is no more true that the change takes place merely because the particles of the organism, the nebula, have weight, tend to gravitate toward each other, than that it takes place merely because the environment, the outside world of matter, is colder than the organism and robs it of its heat. Either alternative is an abstraction from the truth that the two views express phases, set over against each other, of a completed process. Mathematical physics can demonstrate that no smallest fraction of energy is lost or gained by the nebula, except as the quantity of matter in the nebula may change. Energy of molecular or molar motion may become energy of position, or vice versa, but the balance is absolutely conserved. Not only is it true that "action and reaction are equal and opposite in direction," as regards the relation of the nebula to its environment, but also that action and reaction equally occupy one and the same instant of time. It is all one, whether we say that as the environment warms the nebula condenses, or that as the nebula condenses the environment warms. Neither change is first, neither last. To go on,—the condensation of the nebula sets it in rotation. But its own condensation would never make it rotate were it not that the conditions under which the nebula first formed, the varying attractions on different sides from other remote bodies in the environment, the inequalities of heat radiation due to the varying temperatures in different ranges of the outer star-worlds,—all—prevented the nebula from being a perfectly regular homogeneons sphere in which all the particles could gravitate straight toward a center mathematically equidistant from all the points in the outer surface. Either side of the process is effect when the other is made, by abstraction, cause and the side toward which the obbserver's immediate attention is directed determines which side shall be considered causal and which resultant. Water running out of a wash-basin with a central drain-pipe whirls to right or left. But it would not do so were the basin and drain-pipe mathematically exact in construction and the friction of the water upon these environing vessels distributed with ideal regularity. By continued rotation the condensing mass becomes an ellipsoid, then a Jacobian ellipsoid, then a Poincaré's apioid, then

dumb-bell shaped, and finally ruptures into two daughter-masses. The single rotating mother-mass becomes a double-star system. But the relative size and shape of the daughter-masses,—nay, even the very fact that the rotating mother-mass became egg-shaped and so forth, and eventually ruptured, instead of continuing perfectly radically symmetrical about its axis,—all depends not only on the character of the rotating mother-mass but also on the irregular, not ideally balanced, gravitative disturbances of the complex variety of bodies in all environing space. Tidal Friction begins to modify the system as soon as the daughter-masses acquire a rotation of their own either faster or slower than the revolution period they have inherited from the rotation of the mother-mass. Yet even that Tidal Friction is not a force originating simply within the system,—the changed rotation of the two members of the double star depends on the fact that the relation of each of two spheroids to an environing universe cannot be the same as the relation, to even the same environment, of one mass equal to the sum of the two,—if for no other reason, at least because while volume varies as the cube of the mean dimension surface varies as the square, and so halving the volume by no means halves the surface. And then even when the tidal friction history has reached that extreme stage at which the cold dark solid members are revolving in circles far distant from each other, and as if fastened to the ends of a balanced rotating bar, even then, exact cosmogony proves, the disturbing influence, however slight, of other bodies in space, however distant, will begin to turn back the history, and inevitably the members of the double star again approach each other. So no physical system is ever self-consistent, no system can ever be eternal. The "absolutely fixed" is as unknown in cosmic history as in biological. The physical organism and its environment are the two magnet-poles in a sense, of the process of physical evolution. Neither induces the other. Neither can be induced without the other. Some one says: "That environing starry universe existed before your given organism, your given nebula" But the answer is a truism: It was not the same starry universe before even that one nebula existed. Changing somewhat the point of view, we may take either one of the two members of a double star, or a planet-satellite, or a sun-planet system as a single physical organism, and then the other member would become the most important factor in the given organism's environment. This would afford an especially striking opportunity of studying the nicety of the

adjustment of the two functioning parts in a process of physical evolution, and of clearly showing the fallacy of trying to find the source of that process in either of those parts. And there would also be brought out in the most definite form the working principle that there is a clear quantitative relation between an organism and the various factors of its environment, and that some one group of factors, constituting its immediate surroundings, has a determining influence in the organism's development far in excess of any other, or perhaps all other, environment factors. The companion of either star in a double-star system counts for vastly more as an environment factor than any remote bodies in the rest of space. Looking again at the whole life-history cosmogony plots out, one other vital principle might be noted. The process of change in the development of heavenly bodies is markedly of a kind of rhythmic character. There are critical periods of rapid revolutionary change and alternating periods of relatively slow change, of permanence in conditions. In one of the latter stages a large part of the cosmic evolution in our solar system seems to be at the present. All these outline suggestions of principle, though only bare hints of the possibilities of the field, may help to indicate the peculiar clearness, simplicity, and exactness that the mathematical method of astronomy brings to bear upon problems of evolution. Going beneath the mere mathematical formulæ, which are of course purely ideal tools, we find that the new cosmogony has taken up the conception, developed mainly by biology, of evolution as a perpetual flow of change and applied that conception to the subject-matter, and in the method, of the old astronomy of absolute mathematical ideals. Biology has felt the broad spirit of the great law of development, and has partially expressed it; physical science must take the initiative in clearly defining the working principles of that law; and even though those working principles become vastly more complex in the field in which biology labors, they must there reflect the exactness inspired by a study of physical evolution before our theorizing on the processes of organic evolution can become science.

A last thought rises in the story:—The spirit of evolution has entered the domain of physics, chemistry and astronomy; what must it mean for their future? The atoms and molecules and their motions were the fixed presuppositions, the absolute unchanging data, of the older physics; but today the problem of the transformation of energies has brought forth interest in a parallel problem, the transformations of matter, the evolution of

the very atoms and molecules that have been taken as fixed realities. Modern physics is asking:—Whence the atom and the molecule? The broad hypothesis of the light-bearing ether tells us of matter that is non-atomic, and the visible world of atomic matter ceases to be an ultimate physical reality and becomes the product of a process of evolution that carries us back into a world where atoms were yet to be. And in that pre-nebular world our so-called gravitative motion and all the energies that are derived from it were but possibilities of a future. The forms of matter and the forms of motion that physics knows are passing phases in an unending stream of developmental change, and are assumed to be fixed only as a temporary working hypothesis. Again, the chemical elements are no longer the final realities of chemistry. Mendelejeff and Remsen are investigating the evolution, the becoming, of the elements. And, again, so the astronomy whose spirit inspired the *Mécanique Céleste*—"fixed" stars and eternally repeating cycles—is but one side of the truth. A universe of evolving, ever-changing, nebulæ and suns and systems can never be realized in mere mathematical ideals, though it could never become known without them. To make exactness of method a characteristic of scientific thought has been the function of the physical sciences; and now their clear recognition of the law of evolution must reveal to them that their mathematics are only method, that the truth of physical nature, no less than of organic, lies deeper than units of measurement. The chemistry and physics and astronomy that shall express this spirit will know that their task is not merely to describe the world of inorganic things but to write its life-history.

UNIVERSITY OF CHICAGO,
November 20, 1895.

## THE PLANET JUPITER, OPPOSITION 1895-96.

G. W. HOUGH.

FOR POPULAR ASTRONOMY.

The planet Jupiter has been well situated for observation during the past opposition, but during the winter and spring the weather, for a large portion of the time, was unfavorable for good seeing.

In a general way the disk has presented an appearance very similar to the past opposition. The most conspicuous change, however, is in the deepening of the depression in the south edge of

the equatorial belt, immediately below the great red spot, as well as the narrowing of the north edge of the belt.

The diagram, Fig. 2, shows the latitude, corrected for the elevation of the Earth above Jupiter's equator, of the centre of the great red spot and the north and south edges of the equatorial belt, for the past two years.

An examination of this diagram will show more clearly the changes which have taken place in the position of the equatorial belt. The dotted line represents the latitude of the red spot. The south edge of the equatorial belt was nearly stationary in latitude but the north edge drifted towards the equator about 2″.5 of arc. As the width of the north part of the belt was about 3″.5 in October, 1894 and only 1″ in April, 1896 the north edge gradually faded away or disappeared.

Observations on the planet were begun in September, 1895, and continued systematically. The principal spots, whose position have been determined, were the great red spot, two well defined black spots just outside the northerly margin of the equatorial belt, and two dusky black spots on belt No. 3.

The elliptical white spots in the southern hemisphere of the planet were visible but were generally too feeble for good observation of position. The great red spot has been very feeble during the whole opposition of 1895-96. At times the outline could be fairly well seen; being of a pale greenish color, but often the outline could not be traced and the position of the spot could only be indicated by the hollow in the equatorial belt.

The great red spot is undoubtedly periodic as to its visibility and is perhaps more permanent in latitude than any other marking. The mean length of the spot during the earlier years, 1879-86, was 11″.6 of arc. A single measure on Feb. 5, 1896, gave 9″.0. The measures during the last five years make the spot a trifle shorter than formerly, but whether it is due to our inability to see the outline distinctly, or an actual change, I am not certain. If the variation in distinctness is due to a greater or less submergence of the spot below the surface, as I have suggested in a previous paper, the spot might apparently appear longer or shorter without any actual change or size.

From our first observation 1879 to the present time the spot has had a variable retrograde drift on the surface of the planet. The rotation period of the planet given by the red spot in 1879 was $9^h\ 55^m\ 34^s.2$. In 1886 it was $40^s.0$ and 1896, $41^s.4$. Assuming the rotation period of 1879, as a standard for comparison, the spot at the present time has made a little more than two revolutions around the disk.

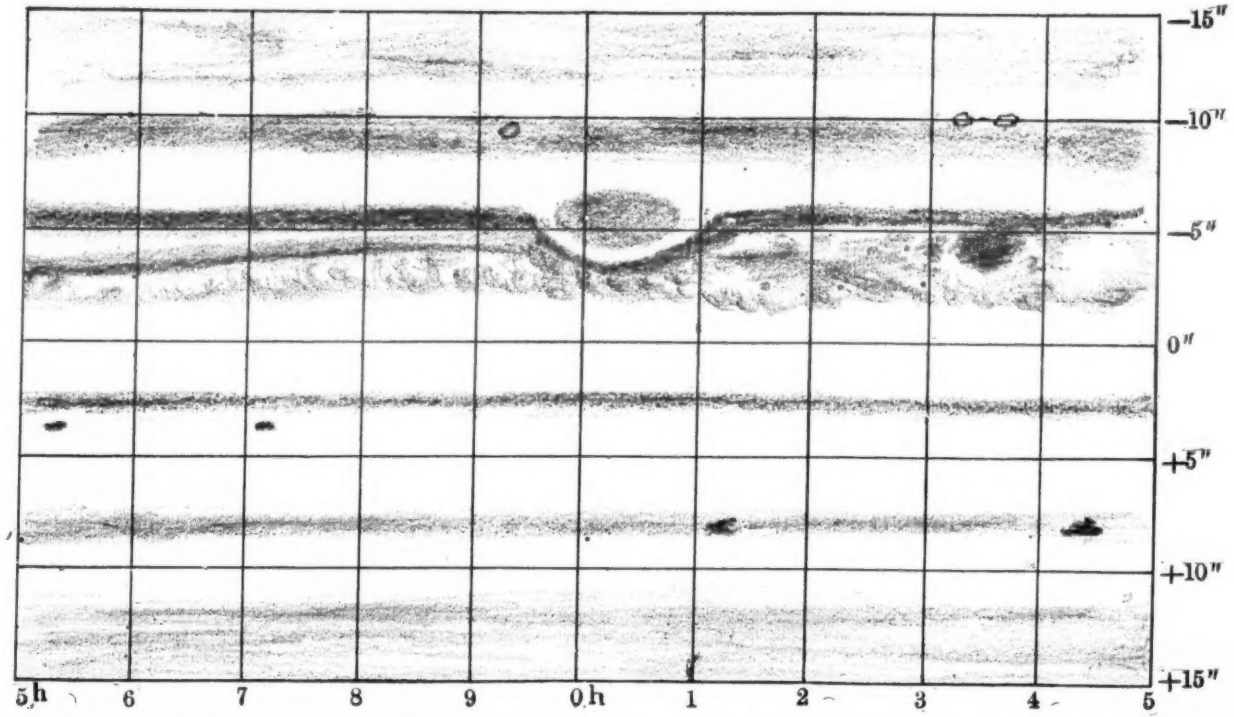



FIG. 1. POSITION OF BELTS AND SPOTS ON JUPITER APRIL 1, 1896. G. W. Hough, Dearborn Observatory, Evanston, Ill.

The "mean" rotation period of the planet given by the red spot from 1879 to 1896, a period of 6,000 days or 14,505 rotations, is $9^h\ 55^m\ 39^s.4$. It is not probable that the spot will continue to retrograde indefinitely, and it will be an event of great interest when it shall come to rest and drift in the opposite direction.

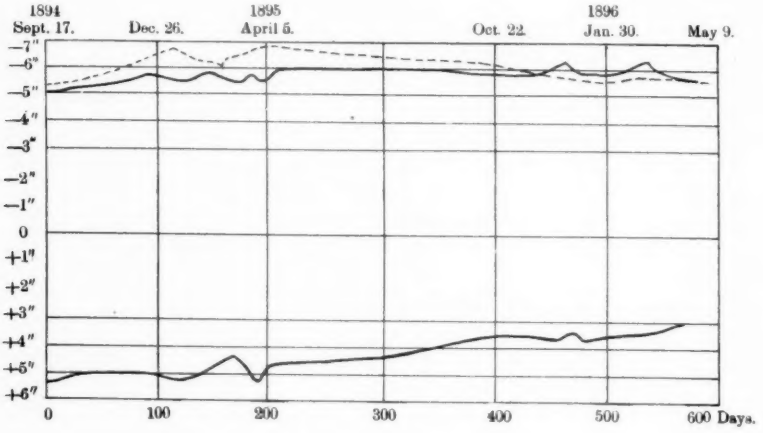



FIG. 2. REDUCED LATITUDE, RED SPOT, EQUATORIAL BELT, JUPITER.

G. W. Hough, Dearborn Observatory, Evanston, Ill.

If continuous observations are made during a complete cycle of its variation in motion, we may be able to get a pretty correct value for the rotation of the planet.

During the opposition of 1894-95, a number of black spots were observed near the north margin of the equatorial belt. Two of these spots have been visible during the present opposition. The spots were about 2″ in length and 1″ in breadth, and were very conspicuous. The following spot was black, and when coming on the disk appeared like the shadow of a satellite.

The spots have a direct drift on the surface of the planet and give an approximate rotation period $9^h\ 55^m\ 34^s$. A dark spot on belt No. 3, 8″.2 north of the apparent equator, observed for an interval of 168 days, gave an approximate rotation period $9^h\ 56^m$; being the slowest moving object that I have ever observed.

The map of Jupiter of April 1, 1896 shows the position of the various spots and belts. Position and size are laid down from

micrometric measurement, but no attempt has been made to show the fine mottling on the equatorial belt.

The white spots near the equator, which were so conspicuous from 1879 to 1886, and gave a rotation period of $9^h\ 50^m$, have not been seen for some years past.

In locating the position of a spot or belt the majority of observers use Jovian latitude which conveys no definite idea as to where the object is to be found on the disk. In order to make a sketch showing the markings on the disk, it is necessary to reconvert Jovicentric or Jovigraphic latitude into seconds of arc. Hence, as I have previously pointed out, it is a decided advantage to indicate latitude by distance north or south of the planet's apparent equator; all quantities being reduced mean distance.

In the study of displacement in latitude, it will be found most convenient to use the direct measures of distance, corrected for the elevation of the Earth above Jupiter's equator. For convenience in observation, it is also desirable to use time in place of degrees, for indicating longitude. I adopted the following nomenclature in 1879, for indicating the position of markings, and have found it a great convenience.

Beginning at the north limb of the disk the various belts are designated as follows:

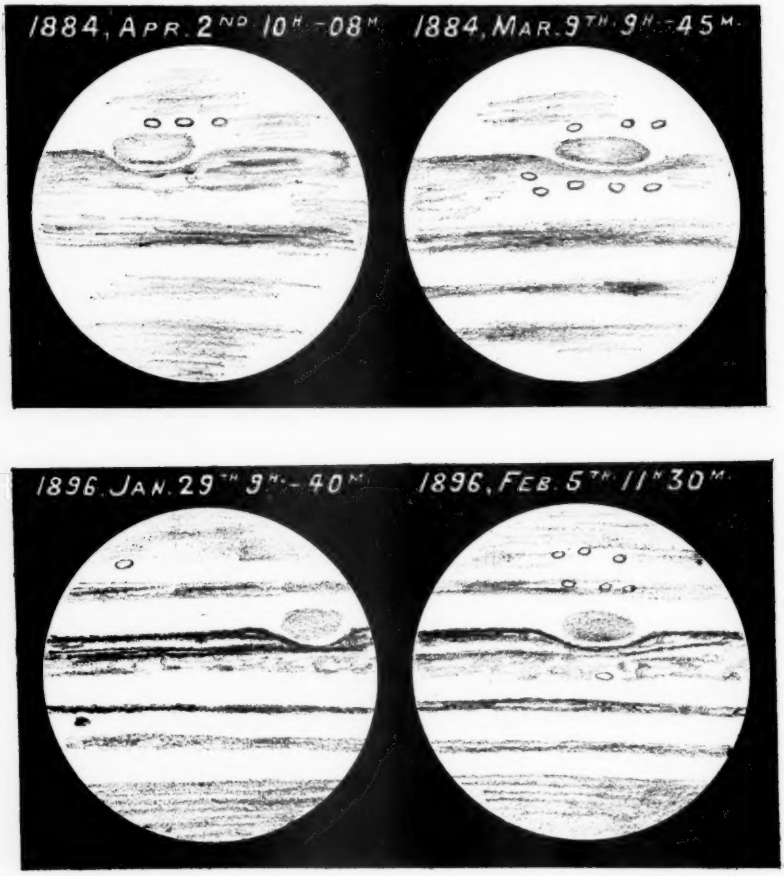
| | | | |
|---|---|---|---|
| B 1. | South edge of shading and limb | + 12″ | App. latitude |
| B 2. | Faint belt | + 10″ | " |
| B 3. | Well defined belt | + 8″ | " |
| B 4. | North edge of the equatorial belt | + 4″ | " |
| B 5. | South edge of the equatorial belt | − 6″ | " |
| B 6. | Well defined belt | − 9″ | " |
| B 7. | North edge of the shading and limb | − 12″ | " |

The apparent distances from the equator are only approximate as the latitude of all markings on the disk is subject to change from year to year. The greatest displacement in latitude is found for B 4 and B 5.

During the past year or two the question of periodicity in Jovian phenomena has been raised, but no definite conclusions have as yet been reached. The problem is one of great difficulty and will require a considerable period of time for its final solution:

If periodicity is due to meteorlogical causes, which is quite possible, we should expect to find phenomena reproduced at intervals corresponding to some function of the Jovian year. As the equator of Jupiter is inclined to its orbit only 3° 06′ the changes of climate would not be very great, but whatever the effect, it should be most marked at intervals of 6 and 12 years.

Sketches or drawings of the planet for deciding any question of change should be used with a good deal of discretion, owing to the personal equation of the observer and instrument. The sketches of one person, using the same telescope and magnifying power, might well be compared *inter se.* and correct conclusions deduced.




THE PLANET JUPITER AT OPPOSITIONS 1884 AND 1896, BY G. W. HOUGH.

A small telescope and low power gives a different picture from that shown by a large telescope and high power. A 4 or 5 inch object glass and power of 100 may show a sharply defined picture of belts and spots, which when viewed with a 12-inch or larger object-glass will appear quite different.

The larger instrument may resolve the belt or marking so as to give an entirely different idea with regard to its constitution. Each instrument has its uses and may afford valuable data to science but the trouble is that we often assume that one sees all that can be seen, when in fact the optical power of the telescope was not sufficient to show the actual phenomena.

The accompanying sketches of the planet Jupiter for 1884 and 1896 an interval approximating a Jovian year, present features showing considerable similarity.

The depression in the south edge of the equatorial belt is nearly the same in both years, and the equatorial belt appears of the same width, but the north part was narrower in 1896 than in 1884. The other belts present a similar appearance except that there is more shading at the north and south limbs of the disk in the latter year.

Observations on the latitude of the edges of the equatorial belt made from 1879 to 1896 indicate a possible periodicity of twelve years, but we need more facts before the condition of the Jovian surface can be correctly interpreted.

Hitherto the attention of observers has been almost entirely given to the study of motion in longitude, or the determination of rotation time. I think we will derive just as important information from the study of motion in latitude. In fact displacement in longitude and latitude should be studied simultaneously.

DEARBORN OBSERVATORY OF NORTHWESTERN UNIVERSITY,
May 9th, 1896.

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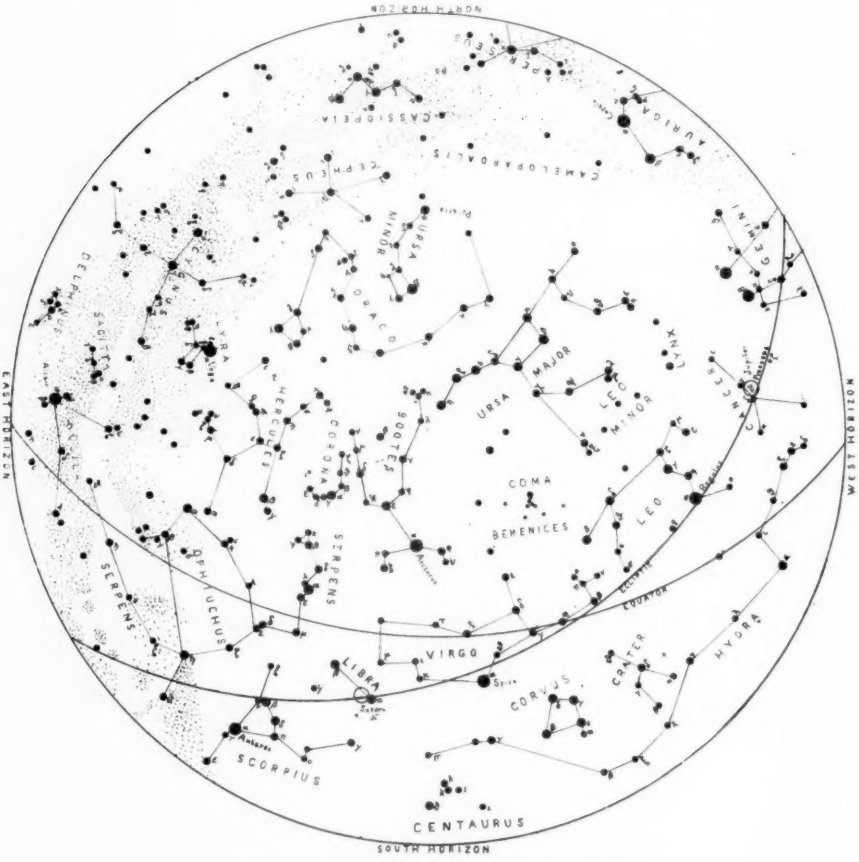
## THE PLANETS AND CONSTELLATIONS FOR JUNE.

*Mercury* will be at inferior conjunction on June 10 and so will not be visible to the naked eye until the latter part of the month, when it will be visible in the southeast as morning star. Mercury and Neptune will be in conjunction on June 14 at $6^h$ P. M. but neither will then be visible because of the overpowering rays of the Sun. Seven hours later Mercury and Venus will be in conjunction and three hours later still, on the same date Venus will pass by Neptune. Of the three planets so nearly in line at this time Mercury will be on the hither side of the Sun and Venus and Neptune on the farther side.

*Mars* is slowly coming into position for observation, crossing the meridian between 7 and 8 o'clock in the morning. The declination of Mars is increasing quite rapidly so that the situation of the planet will be far more favorable this summer than last. The apparent diameter of Mars is now about 7″ so that observers with good telescopes and atmosphere ought to be able to see some of the more prominent markings on the planet. The Moon will pass 5° to the north of Mars on June 4 at $3^h$ $37^m$ P. M. Central Standard Time.

*Jupiter* will be pretty well down in the west by dark during June, but good views may be obtained in early twilight. On June 14 at $3^h\ 12^m$ Central Standard Time, the Moon will pass close north of Jupiter. In northern latitudes of North America an occultation of the planet might be witnessed, were it not for the bright sunlight at this hour of the day. In the Journal of the British Astronomical Association, Vol. VI, No. 6, Mr. Leo Brenner calls attention to a number of




THE CONSTELLATIONS AT $9^h$ P. M. JUNE 1, 1896.

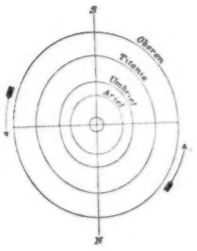
changes in the belts of Jupiter during the past months and asks observers to notice the great activity of the N. N. temperate belt, where there are now a dozen dark spots. Mr. C. Roberts thinks the longitude of the centre of the Great Red Spot is increasing. Rev. T. H. Foulkes asks if other observers have noticed a *pulsating movement* of the region around the red spot. He says that he has noticed it long before the spot was on the disk and could tell that the spot was coming on because of this *fluttering* movement, without reference to Mr. Marth's tables or to the well-known features of the planet.

*Saturn* will be in good position for evening observation in June. The place of Saturn among the stars is shown upon our chart for this month. It is near the star $\alpha$ Libræ but is much brighter than the star. Saturn's motion will be slow, westward during the month. The Moon will pass about 8° south of Saturn on the afternoon of June 21.

*Uranus* is 7° east and 4° south of Saturn. On June 1 its right ascension is $15^h\ 17^m$ and its declination south 17° 56′. Its motion is slow, westward. Professor E. E. Barnard has recently published the results of his measures of the system of Uranus with the great Lick telescope. His measures of the planet show ellipticity of its form, the polar diameter coming out 3″.93 and the equatorial 4″.15. These results agree very closely with those obtained by Professor Young in 1883 with the 23-inch Princeton telescope. It is interesting to note that the two inner satellites Ariel and Umbriel were always difficult objects even with the 36-inch telescope and the keen eye of Barnard.

*Neptune* is behind the Sun, superior conjunction occurring June 7.

## The Satellites of Uranus.




ARIEL.

| North. | | South. | |
|---|---|---|---|
| June 2 | 2.5 P. M. | June 1 | 8.2 A. M. |
| 5 | 3.0 A. M. | 3 | 8.7 P. M. |
| 7 | 3.5 P. M. | 6 | 9.2 A. M. |
| 10 | 4.0 A. M. | 8 | 9.7 P. M. |
| 12 | 4.5 P. M. | 11 | 10.2 A. M. |
| 15 | 5.0 A. M. | 13 | 10.7 P. M. |
| 17 | 5.5 P. M. | 16 | 11.2 A. M. |
| 20 | 6.0 A. M. | 18 | 11.7 P. M. |
| 22 | 6.5 P. M. | 21 | 12.2 P. M. |
| 25 | 7.0 A. M. | 24 | 12.7 A. M. |
| 27 | 7.5 P. M. | 26 | 1.2 P. M. |
| 30 | 8.0 A. M. | 29 | 1.7 A. M. |

TITANIA.

| North. | | South. | |
|---|---|---|---|
| June 2 | 11.3 A. M. | June 6 | 7.8 P. M. |
| 11 | 4.3 " | 15 | 12.8 " |
| 19 | 9.4 P. M. | 24 | 5.8 A. M. |
| 28 | 2.4 " | | |

OBERON.

| | | | |
|---|---|---|---|
| June 5 | 9.3 P. M. | June 12 | 3.0 P. M. |
| 19 | 8.7 A. M. | 26 | 2.3 A. M. |

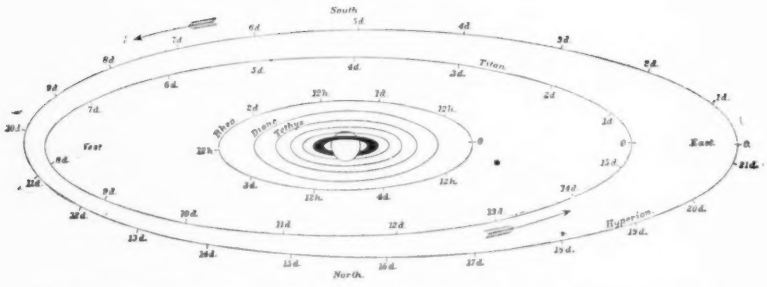
UMBRIEL.

| North. | | South. | |
|---|---|---|---|
| June 4 | 7.8 A. M. | June 2 | 6.1 A. M. |
| 8 | 11.3 " | 6 | 9.6 " |
| 12 | 2.8 P. M. | 10 | 1.1 P. M. |
| 16 | 6.3 " | 14 | 4.6 " |
| 20 | 9.8 " | 18 | 8.0 " |
| 25 | 1.2 A. M. | 22 | 11.5 " |
| 29 | 4.7 " | 27 | 3.0 A. M. |

## Occultations Visible at Washington.

| Date 1896. | Star's Name. | Magnitude. | IMMERSION. Washington M. T. h | m | Angle f'm N pt. ° | EMERSION. Washington M. T. h | m | Angle f'm N pt. ° | Duration. h | m |
|---|---|---|---|---|---|---|---|---|---|---|
| June 7 | $\mu$ Arietis*.....6 0 | | 13 | 44 | 73 | 14 | 35 | 241 | 0 | 51 |
| 13 | 7 Cancri* .....6.3 | | 9 | 49 | 113 | 10 | 36 | 285 | 0 | 47 |
| 28 | $\mu$ Capricorni*... 5.2 | | 9 | 1 | 2 | 9 | 23 | 319 | 0 | 22 |
| 30 | 11 Piscium.....6.4 | | 13 | 18 | 73 | 14 | 33 | 213 | 1 | 15 |
| 30 | 13 Piscium.....6.4 | | 15 | 48 | 37 | 17 | 12 | 239 | 1 | 24 |
| July 3 | 104 Piscium.....7 5 | | 13 | 31 | 84 | 14 | 29 | 215 | 0 | 58 |
| 4 | 26 Arietis.....6 0 | | 17 | 8 | 178 | 17 | 50 | 295 | 0 | 42 |
| 11 | B. A. C. 3103*...7 5 | | 17 | 45 | 170 | 18 | 4 | 218 | 0 | 19 |
| 11 | Jupiter..... | | 18 | 58 | 120 | 19 | 52 | 271 | 0 | 54 |
| 25 | 44 Capricorni....6.1 | | 14 | 4 | 179 | 14 | 53 | 286 | 0 | 49 |
| 25 | 45 Capricorni....6.3 | | 14 | 1 | 109 | 14 | 45 | 176 | 0 | 44 |
| 28 | 21 Piscium*.....5.8 | | 8 | 38 | 45 | 9 | 33 | 290 | 0 | 55 |

## Saturn's Satellites.




[In the diagram the points marked 0 are those of eastern elongation as seen in an inverting telescope, and those marked 1d, 2d, etc. represent the positions of the satellites at intervals of one day, two days, etc. after the times of eastern elongation. E = east elongation. I = inferior conjunction (south of planet). W = west elongation. S = superior conjunction (north of planet).]

### MIMAS.

| | | h | | |
|---|---|---|---|---|
| June | 1 | 10.4 | P. M. | E |
| | 2 | 9.0 | " | E |
| | 3 | 7.7 | " | W |
| | 7 | 2.8 | A. M. | W |
| | 8 | 1.4 | " | W |
| | 8 | 12.0 | midn. | W |
| | 9 | 10.6 | P. M. | W |
| | 10 | 9.2 | " | W |
| | 11 | 7.8 | " | W |
| | 17 | 12.2 | A. M. | E |
| | 17 | 10.8 | P. M. | E |
| | 18 | 9.4 | " | E |
| | 19 | 8.1 | " | E |
| | 25 | 10.4 | " | W |
| | 26 | 9.0 | " | W |
| | 27 | 7.6 | " | W |

### ENCELADUS.

| | | h | | |
|---|---|---|---|---|
| June | 1 | 5.0 | A. M. | E |
| | 2 | 1.9 | P. M. | E |
| | 3 | 10.8 | " | E |
| | 5 | 7.7 | A. M. | E |
| | 6 | 4.6 | P. M. | E |
| | 8 | 1.5 | A. M. | E |
| | 9 | 10.4 | " | E |
| | 10 | 7.3 | P. M. | E |
| | 12 | 4.1 | A. M. | E |
| | 13 | 1.0 | P. M. | E |
| | 14 | 9.9 | " | E |
| | 16 | 6.8 | A. M. | E |
| | 17 | 3.6 | P. M. | E |
| | 19 | 12.5 | A. M. | E |
| | 20 | 9.4 | " | E |
| | 21 | 6.3 | P. M. | E |

### ENCELADUS CONT.

| | | h | | |
|---|---|---|---|---|
| | 23 | 3.1 | A. M. | E |
| | 24 | 12.0 | M. | E |
| | 25 | 8.9 | P. M. | E |
| | 27 | 5.7 | A. M. | E |
| | 28 | 2.6 | P. M. | E |
| | 29 | 11.5 | " | E |
| July | 1 | 8.4 | A. M. | E |

### TETHYS.

| | | h | | |
|---|---|---|---|---|
| June | 2 | 4.5 | P. M. | E |
| | 4 | 1.8 | " | E |
| | 6 | 11.1 | A. M. | E |
| | 8 | 8.3 | " | E |
| | 10 | 5.6 | " | E |
| | 12 | 2.8 | " | E |
| | 14 | 12.1 | " | E |
| | 15 | 9.4 | P. M. | E |
| | 17 | 6.8 | " | E |
| | 19 | 4.1 | " | E |
| | 21 | 1.4 | " | E |
| | 23 | 10.7 | A. M | E |
| | 25 | 8.0 | " | E |
| | 27 | 5.3 | " | E |
| | 29 | 2.6 | " | E |
| | 30 | 11.9 | P. M. | E |

### DIONE.

| | | h | | |
|---|---|---|---|---|
| June | 1 | 11.1 | P. M. | E |
| | 4 | 4.7 | " | E |
| | 7 | 10.3 | A. M. | E |
| | 10 | 4.0 | " | E |
| | 12 | 9.6 | P. M. | E |
| | 15 | 3.3 | " | E |
| | 18 | 9.0 | A. M. | E |

### DIONE CONT.

| | | h | | |
|---|---|---|---|---|
| June | 21 | 2.7 | A. M. | E |
| | 23 | 8.3 | P. M. | E |
| | 26 | 2.0 | " | E |
| | 29 | 7.7 | A. M. | E |

### RHEA.

| | | h | | |
|---|---|---|---|---|
| June | 1 | 8.5 | P. M. | E |
| | 6 | 8.8 | A. M. | E |
| | 10 | 9.2 | P. M. | E |
| | 15 | 9.5 | A. M. | E |
| | 19 | 9.9 | P. M. | E |
| | 24 | 10.2 | A. M. | E |
| | 28 | 10.6 | P. M. | E |

### TITAN.

| | | h | | |
|---|---|---|---|---|
| June | 3 | 10.7 | A. M. | E |
| | 7 | 7.5 | " | I |
| | 11 | 11.8 | " | W |
| | 15 | 12.5 | P. M. | S |
| | 19 | 7.5 | A. M. | E |
| | 23 | 4.4 | " | I |
| | 27 | 8.5 | " | W |

### HYPERION.

| | | h | | |
|---|---|---|---|---|
| June | 4 | 12.7 | A. M. | I |
| | 8 | 7.5 | P. M. | W |
| | 13 | 8.3 | A. M. | S |
| | 19 | 2.0 | " | E |
| | 25 | 5.9 | " | I |
| | 30 | 12.9 | " | W |

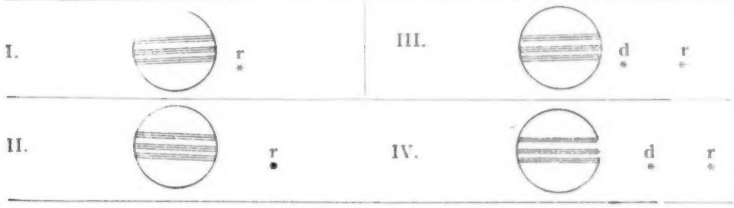
### IAPETUS.

| | | h | | |
|---|---|---|---|---|
| June | 13 | 10.7 | A. M. | E |
| July | 1 | 9.5 | " | I |

## Jupiter's Satellites for June.

Central Standard Time.

*Phases of the Eclipses of the Satellites for an Inverting Telescope.*




*Configuration 8h 0m p. m. for an Inverting Telescope.*

| Day. | West. | East. |
|---|---|---|
| 1 | ·2 ·4 | ○ 3· ·1● |
| 2 | 1· ·3○ | ·2·4 |
| 3 | 3· | ○ ·1 2· ·4 |
| 4 | ·3 2· 1· | ○ ·4 |
| 5 | 2· ·3 | ○ 1· ·4 |
| 6 | ·1 | ○ ·3 ·2 4· |
| 7 | | ○ 2· 1· ·3 4· |
| 8 | 2· ·1 | ○ 3· 4· |
| 9 | 1· | ○3· 4· ·2● |
| 10 | 3· | ○4· ·1 2· |
| 11 | ·3 4· 1·2· | ○ |
| 12 | 4· ·2 ·3 | ○ ·1 |
| 13 | 4· ·1 | ○ ·3 ·1 |
| 14 | 4· | ○ 2· 1· ·3 |
| 15 | ·4 2· ·1 | ○ 3· |
| 16 | ○1· ·4 ·2 | ○ 3· |
| 17 | ·4 3· | ○ ·1 2. |
| 18 | 3· ·4 1· 2· | ○ |
| 19 | 3· ·2 | ○ ·4 ·1 |
| 20 | 1. | ○ ·3 ·2 ·4 |
| 21 | | ○ 1·2· ·3 ·4 |
| 22 | 2· ·1 | ○ 3· 4· |
| 23 | ·2 | ○ 1· 3· 4· |
| 24 | 3· | ○ 2· 4· ·1● |
| 25 | ○2· 3· 1· | ○ 4· |
| 26 | 3· ·2 | ○ ·1 4· |
| 27 | ○4· 1· | ○ ·2 ·3● |
| 28 | 4· | ○ 1· 2· ·3 |
| 29 | 4· 2· ·1 | ○ 3· |
| 30 | 4· ·2 | ○ 1· 3· |

## Phenomena of Jupiter's Satellites.

Central Time.

| | | h | m | | | |
|---|---|---|---|---|---|---|
| June | 1 | 6 | 13 P. M. | I | Oc. | Dis. |
| | | 9 | 34 " | I* | Ec. | Re. |
| | 2 | 10 | 12 A. M. | IV | Oc. | Dis. |
| | | 2 | 57 P. M. | IV | Oc. | Re. |
| | | 3 | 27 " | I | Tr. | In. |
| | | 3 | 31 " | II | Oc. | Dis. |
| | | 3 | 57 " | III | Tr. | In. |
| | | 4 | 29 " | I | Sh. | In. |
| | | 5 | 47 " | I | Tr. | Eg. |
| | | 6 | 49 " | I | Sh. | Eg. |
| | | 7 | 36 " | III* | Tr. | Eg. |
| | | 8 | 5 " | III* | Sh. | In. |
| | | 8 | 6 " | IV* | Ec. | Dis. |
| | | 8 | 26 " | II* | Ec. | Re. |
| | | 11 | 48 " | III | Sh. | Eg. |
| | 3 | 12 | 52 A. M. | IV | Ec. | Re. |
| | | 12 | 43 P. M. | I | Oc. | Dis. |
| | | 4 | 3 " | I | Ec. | Re. |
| | 4 | 9 | 57 A. M. | I | Tr. | In. |
| | | 10 | 20 " | II | Tr. | In. |
| | | 10 | 57 " | I | Sh. | In. |
| | | 12 | 17 P. M. | I | Tr. | Eg. |
| | | 12 | 18 " | II | Sh. | In. |
| | | 1 | 16 " | II | Tr. | Eg. |
| | | 1 | 17 " | I | Sh. | Eg. |
| | | 3 | 14 " | II | Sh. | Eg. |
| | 5 | 7 | 13 A. M. | I | Oc. | Dis. |
| | | 10 | 32 " | I | Ec. | Re. |
| | 6 | 4 | 27 " | I | Tr. | In. |
| | | 4 | 53 " | II | Oc. | Dis. |
| | | 5 | 26 " | I | Sh. | In. |
| | | 6 | 4 " | III | Oc. | Dis. |
| | | 6 | 47 " | I | Tr. | Eg. |
| | | 7 | 45 " | I | Sh. | Eg. |
| | | 9 | 43 " | II | Ec. | Re. |
| | | 9 | 44 " | III | Oc. | Re. |
| | | 10 | 8 " | III | Ec. | Dis. |
| | | 1 | 42 P. M. | III | Ec. | Re. |
| | 7 | 1 | 43 A. M. | I | Oc. | Dis. |
| | | 5 | 0 " | I | Ec. | Re. |
| | | 10 | 57 P. M. | I | Tr. | In. |
| | | 11 | 43 " | II | Tr. | In. |
| | | 11 | 55 " | I | Sh. | In. |
| | 8 | 1 | 17 A. M. | I | Tr. | Eg. |
| | | 1 | 37 " | II | Sh. | In. |
| | | 2 | 15 " | I | Sh. | Eg. |
| | | 2 | 39 " | II | Tr. | Eg. |
| | | 4 | 34 " | II | Sh. | Eg. |
| | | 8 | 13 P. M. | I* | Oc. | Dis. |
| | | 11 | 29 " | I | Ec. | Re. |
| | 9 | 5 | 27 " | I | Tr. | In. |
| | | 6 | 15 " | II | Oc. | Dis. |
| | | 6 | 24 " | I | Sh. | In. |
| | | 7 | 47 " | I* | Tr. | Eg. |
| | | 8 | 15 " | III* | Tr. | In. |
| | | 8 | 44 " | I | Sh. | Eg. |
| | | 11 | 0 " | II | Ec. | Re. |
| | | 11 | 55 " | III | Tr. | Eg. |
| | 10 | 12 | 2 A. M. | III | Sh. | In. |
| | | 3 | 47 " | III | Sh. | Eg. |
| | 10 | 2 | 43 P. M. | I | Oc. | Dis. |
| | | 5 | 58 " | I | Ec. | Re. |
| | | 7 | 13 " | IV* | Tr. | In. |
| | | 12 | 00 midn. | IV | Tr. | Eg. |
| | 11 | 4 | 6 A. M. | IV | Sh. | In. |
| | | 9 | 1 " | IV | Sh. | Eg. |
| | | 11 | 56 " | I | Tr. | In. |
| | | 12 | 52 " | I | Sh. | In. |
| | | 1 | 7 P. M. | II | Tr | In. |
| | | 2 | 16 " | I | Tr. | Eg. |
| | | 2 | 56 " | II | Sh. | In. |
| | | 3 | 12 " | I | Sh. | Eg. |
| | | 4 | 3 " | II | Tr. | Eg. |
| | | 5 | 52 " | II | Sh. | Eg. |
| | 12 | 9 | 14 A. M. | I | Oc. | Dis. |
| | | 12 | 27 P. M. | I | Ec. | Re. |
| | 13 | 6 | 26 A. M. | I | Tr. | In. |
| | | 7 | 21 " | I | Sh. | In. |
| | | 7 | 37 " | II | Oc. | Dis. |
| | | 8 | 46 " | I | Tr. | Eg. |
| | | 9 | 41 " | I | Sh. | Eg. |
| | | 10 | 25 " | III | Oc. | Dis. |
| | | 12 | 18 P. M. | II | Ec. | Re. |
| | | 2 | 5 " | III | Oc. | Re. |
| | | 2 | 8 " | III | Ec. | Dis. |
| | | 5 | 42 " | III | Ec. | Re. |
| | 14 | 3 | 44 A. M. | I | Oc. | Dis. |
| | | 6 | 56 " | I | Ec. | Re. |
| | 15 | 12 | 56 " | I | Tr. | In. |
| | | 1 | 49 " | I | Sh. | In. |
| | | 2 | 31 " | II | Tr. | In. |
| | | 3 | 16 " | I | Tr. | Eg. |
| | | 4 | 9 " | I | Sh. | Eg. |
| | | 4 | 14 " | II | Sh. | In. |
| | | 5 | 27 " | II | Tr. | Eg. |
| | | 7 | 11 " | II | Sh. | Eg. |
| | | 10 | 14 P. M. | I | Oc. | Dis. |
| | 16 | 1 | 24 A. M. | I | Ec. | Re. |
| | | 7 | 26 P. M. | I* | Tr. | In. |
| | | 8 | 18 " | I* | Sh. | In. |
| | | 9 | 0 " | II | Oc. | Dis. |
| | | 9 | 46 " | I | Tr. | Eg. |
| | | 10 | 38 " | I | Sh. | Eg. |
| | 17 | 12 | 35 A. M. | III | Tr. | In. |
| | | 1 | 35 " | II | Ec. | Re. |
| | | 4 | 3 " | III | Sh. | In |
| | | 4 | 16 " | III | Tr. | Eg. |
| | | 7 | 46 " | III | Sh. | Eg. |
| | | 4 | 44 P. M. | I | Oc. | Dis. |
| | | 7 | 53 " | I* | Ec. | Re. |
| | 18 | 1 | 56 " | I | Tr. | In. |
| | | 2 | 47 " | I | Sh. | In. |
| | | 3 | 55 " | II | Tr. | In. |
| | | 4 | 16 " | I | Tr. | Eg. |
| | | 5 | 7 " | I | Sh. | Eg. |
| | | 5 | 33 " | II | Sh. | In. |
| | | 6 | 51 " | II | Tr. | Eg. |
| | | 8 | 29 " | II* | Sh. | Eg. |
| | 19 | 7 | 11 A. M. | IV | Oc | Dis. |
| | | 10 | 58 " | IV | Oc. | Re. |

| | | | | | |
|---|---|---|---|---|---|
| 19 | 11 | 14 | A. M. | I | Oc. Dis. |
| | 2 | 8 | P. M. | IV | Ec. Dis. |
| | 2 | 22 | " | I | Ec. Re. |
| | 6 | 55 | " | IV* | Ec. Re. |
| 20 | 8 | 26 | A. M. | I | Tr. In. |
| | 9 | 15 | " | I | Sh. In. |
| | 10 | 23 | " | II | Oc. Dis. |
| | 10 | 46 | " | I | Tr. Eg. |
| | 11 | 36 | " | I | Sh. Eg. |
| | 2 | 46 | P. M. | III | Oc. Dis. |
| | 2 | 52 | " | II | Ec. Re. |
| | 9 | 42 | " | III | Ec. Re. |
| 21 | 5 | 44 | A. M. | I | Oc. Dis. |
| | 8 | 51 | " | I | Ec. Re. |
| 22 | 2 | 56 | " | I | Tr. In. |
| | 3 | 44 | " | I | Sh. In. |
| | 5 | 16 | " | I | Tr. Eg. |
| | 5 | 19 | " | II | Tr. In. |
| | 6 | 4 | " | I | Sh. Eg. |
| | 6 | 52 | " | II | Sh. In. |
| | 8 | 15 | " | II | Tr. Eg. |
| | 9 | 48 | " | II | Sh. Eg. |
| 23 | 12 | 15 | " | I | Oc. Dis. |
| | 3 | 19 | " | I | Ec. Re. |
| | 9 | 26 | P. M. | I | Tr. In. |
| | 10 | 12 | " | I | Sh. In. |
| | 11 | 46 | " | II | Oc. Dis. |
| | 11 | 46 | " | I | Tr. Eg. |
| 24 | 12 | 32 | A. M. | I | Sh. Eg. |
| | 4 | 9 | " | II | Ec. Re. |
| | 4 | 58 | " | III | Tr. In. |
| | 8 | 3 | " | III | Sh. In. |
| | 8 | 39 | " | III | Tr. Eg. |
| | 11 | 45 | " | III | Sh. Eg. |
| | 6 | 45 | P. M. | I | Oc. Dis. |
| | 9 | 48 | " | I | Ec. Re. |
| 25 | 3 | 56 | " | I | Tr. In. |
| | 4 | 41 | " | I | Sh. In. |
| | 6 | 18 | " | I | Tr. Eg. |
| | 6 | 43 | " | II | Tr. In. |
| | 7 | 1 | " | I* | Sh. Eg. |
| | 8 | 10 | " | II | Sh. In. |
| | 9 | 39 | " | II | Tr. Eg. |
| | 11 | 6 | " | II | Sh. Eg |
| 26 | 1 | 15 | P. M. | I | Oc. Dis. |
| | 4 | 17 | " | I | Ec. Re. |
| 27 | 10 | 26 | A. M. | I | Tr. In. |
| | 11 | 9 | " | I | Sh. In. |
| | 12 | 46 | P. M. | I | Tr. Eg. |
| | 1 | 9 | " | II | Oc. Dis. |
| | 1 | 29 | " | I | Sh. Eg. |
| | 4 | 20 | " | IV | Tr. In. |
| | 5 | 27 | " | II | Ec. Re. |
| | 7 | 9 | " | III | Oc. Dis. |
| | 8 | 10 | " | IV | Tr. Eg. |
| | 10 | 7 | " | IV | Sh. In. |
| 28 | 1 | 41 | A. M. | III | Ec. Re. |
| | 3 | 2 | " | IV | Sh. Eg. |
| | 7 | 45 | " | I | Oc. Dis. |
| | 10 | 46 | " | I | Ec. Re. |
| 29 | 4 | 56 | " | I | Tr. In. |
| | 5 | 38 | " | I | Sh. In. |
| | 7 | 16 | " | I | Tr. Eg. |
| | 7 | 58 | " | I | Sh. Eg. |
| | 8 | 7 | " | II | Tr. In. |
| | 9 | 29 | " | II | Sh. In. |
| | 11 | 3 | " | II | Tr. Eg. |
| | 12 | 25 | P. M. | II | Sh. Eg. |
| 30 | 2 | 16 | A. M. | I | Oc. Dis. |
| | 5 | 14 | " | I | Ec. Re. |
| | 11 | 27 | P. M. | I | Tr. In. |
| 31 | 12 | 7 | A. M. | I | Sh. In. |
| | 1 | 47 | " | I | Tr. Eg. |
| | 2 | 27 | " | I | Sh. Eg. |
| | 2 | 32 | " | II | Oc. Dis. |
| | 6 | 44 | " | II | Ec. Re. |
| | 9 | 22 | " | III | Tr. In. |

## Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time.]

ALGOL.

1896.

| | d | h |
|---|---|---|
| July | 1 | 15 |
| | 15 | 23 |
| | 18 | 20 |
| | 21 | 17 |
| | 24 | 14 |

U CEPHEI.

1896.

| | d | h |
|---|---|---|
| July | 2 | 13 |
| | 30 | 0 |

U CORONÆ.

| | | |
|---|---|---|
| July | 6 | 22 |
| | 13 | 20 |
| | 20 | 18 |
| | 27 | 15 |

U OPHIUCHI.

1896.

| | d | h |
|---|---|---|
| July | 1 | 18 |
| | 2 | 15 |
| | 6 | 19 |
| | 7 | 15 |
| | 11 | 20 |
| | 12 | 16 |
| | 13 | 12 |

W DELPHINI.

(D.M.+17°,4367.)

1896.

| | d | h |
|---|---|---|
| July | 1 | 10 |
| | 6 | 5 |
| | 11 | 1 |
| | 15 | 20 |
| | 20 | 15 |
| | 25 | 11 |
| | 30 | 6 |

From Hartwig's ephemeris in the *Vierteljahrsschrift* except that for W Delphini I have used Pickering's ephemeris in the March *Astrophysical Journal.*

J. A. PARKHURST.

Marengo, Ill., May 8, 1896.

## Maxima and Minima of Long Period Variables.

MAXIMA.

1896 August.

| Date | No. | Star. |
|---|---|---|
| 1 | 5758 | X Herculis |
| 2 | 5761 | Z Scorpii |
| 3 | 3477 | R Leonis min. |
| 4 | 4521 | R Virginis |
| 4 | 5037 | RR Virginis |
| 6 | 3060 | U Cancri |
| 8 | 8068 | S Lacertæ |
| 8 | 6943 | T Sagittæ |
| 10 | 4948 | R Canum ven. |

MAXIMA CONT.

1896 August.

| Date | No. | Star. |
|---|---|---|
| 15 | 7192 | Z Cygni |
| 16 | 7404 | R Microscopii |
| 19 | 5157 | S Bootis |
| 19 | 6512 | T Herculis |
| 21 | 5338 | U Bootis |
| 21 | 4377 | T Virginis |
| 23 | 8512 | R Aquarii |
| 24 | 7909 | S Piscis aus. |

MINIMA.

1896 August.

| Date | No. | Star. |
|---|---|---|
| 3 | 5190 | RCamelopard |
| 5 | 7242 | S Aquilæ |
| 7 | 3493 | R Leonis |
| 7 | 1574 | W Tauri |
| 14 | 513 | R Piscium |
| 17 | 1944 | S Orionis |
| 17 | 1717 | V Tauri |
| 25 | 1577 | R Tauri |

## Ephemeris of Short-Period Variables.

JUNE, 1896.

[Greenwich Mean Time].

4805 W VIRGINIS.

| Max. | Min. |
|---|---|
| 16.23 | 8.03 |
| | 25.30 |

6758 $\beta$ LYRÆ.

| | |
|---|---|
| | 13.16 |
| | 26.08 |

6368 X SAGITTARII.

| | |
|---|---|
| 4.71 | 1.83 |
| 11.72 | 8.84 |
| 18.73 | 15.85 |
| 25.74 | 22.87 |

6404 Y OPHIUCHI.

| | |
|---|---|
| 17.37 | 11.12 |
| | 28.24 |

6472 W SAGITTARII.

| | |
|---|---|
| 6.32 | 3.32 |
| 13.92 | 10.92 |
| 21.51 | 18.51 |
| 29.11 | 26.11 |

6573 Y SAGITTARII.

| Max. | Min. |
|---|---|
| 2.99 | 1.19 |
| 8.77 | 6 97 |
| 14.54 | 12.74 |
| 20.31 | 18.51 |
| 26.08 | 24.28 |
| | 30.06 |

6636 U SAGITTARII.

| | |
|---|---|
| 3.42 | |
| 10.16 | 7.19 |
| 16 91 | 13 94 |
| 23 65 | 20 68 |
| 30.40 | 27.42 |

6984 U AQUILAE.

| | |
|---|---|
| 7.50 | 5.25 |
| 14.53 | 12.28 |
| 21.56 | 19.31 |
| 28.58 | 26.33 |

7124 $\eta$ AQUILAE.

| | |
|---|---|
| 5.64 | 3.26 |
| 12 82 | 10.44 |
| 19.99 | 17 61 |
| 27.17 | 24.79 |

7149 S SAGITTÆ.

| Max. | Min. |
|---|---|
| 7.94 | 4.54 |
| 16.32 | 12.92 |
| 24.70 | 21.30 |

7437 X CYGNI.

| | |
|---|---|
| 3.19 | |
| 19.57 | 12.77 |
| | 29.16 |

7483 T VULPECULÆ.

| | |
|---|---|
| 1.88 | |
| 6.32 | 5.02 |
| 10.75 | 9.45 |
| 15.19 | 13.89 |
| 19 63 | 18.33 |
| 24.06 | 22.76 |
| 28 50 | 27.20 |
| | 29.63 |

8073 $\delta$ CEPHEI.

| | |
|---|---|
| 4.86 | 3.27 |
| 10 22 | 8.63 |
| 15.59 | 14.00 |
| 20.96 | 19.37 |
| 26.32 | 24.73 |

## VARIABLE STAR NOTES.

**Dr. S. C. Chandler** has begun the preparation of his third catalogue of variables. Less than three years have elapsed since the publication of the second catalogue, but the great activity in this work has made a third edition necessary.

**2815 U Geminorum.**—Mr. W. E. Sperra succeeded in getting five observations of this irregular star near its last maximum, which he locates at March 17.23 Greenwich mean time. The interval from the last recorded maximum is 141 days, which perhaps includes two periods.

**Professor E. E. Barnard** proposes to follow some of the fainter variables with the 40-inch Yerkes telescope to ascertain the character of their change near minimum. The results of this investigation will be of great interest, as many variables go below the limits of the apertures used in the work. The largest telescope heretofore systematically used in this work is the 15-inch of the Washburn Observatory, with which Mr. S. D. Townley made an important series of observations in 1889-92.

**A Systematic Error in Visual Observations.**—Dr. S. C. Chandler, in *Astronomical Journal*, No. 374, warns observers against "the systematic effect, arising from unequal sensitiveness of different portions of the retina, dependent on varying position of the variable relative to its comparison stars in different hour-angles." Various methods have been followed to eliminate this effect. Professor Roberts uses a reversing prism in front of the eye-piece, and makes two observations, one in the direct, the other in the reversed position of the stars. With a reflecting telescope this error can easily be avoided, since by turning the tube in the cradle the line joining the stars can be brought into a horizontal position; one of the numerous advantages which make the reflector almost an ideal instrument for variable star work.

**Photometric Versus Visual Observations.**—Professor E. C. Pickering published an article in the April *Astrophysical Journal* on "Light Curve of Variable Stars Determined Photometrically," in which he discusses the relative merits of the two methods of observations, concluding that, "In any careful study of the causes of the variation of different stars, photometric measures are almost indispensable. Argelander's method . . . serves very well in determining the period of the variation." The following determinations of the last maximum of 103 T Andromedæ are submitted as bearing on the question.

| Photometric. | | Visual. | |
|---|---|---|---|
| Date. | Observer. | Date. | Observer. |
| 1895, Aug. 25 | H. M. Parkhurst | 1895, Aug. 31.5 | P. S. Yendell |
| Sept. 12 | E. Lindemann | Sept. 1 | Walter J. Gill |
| Sept. 15 | E. C. Pickering | Sept. 7.5 | W. E. Sperra |
| | | Sept. 8.6 | J. A. Parkhurst. |

It will be noticed that the visual determinations are included within an interval of 8 days, while the dates determined photometrically cover a period of 21 days.

J. A. PARKHURST.

**Ephemeris of Comet *c* 1895, (Perrine).**

[From *Astronomical Journal* No. 374]

| | | R. A. | | | Decl. | | log *r* | log $\Delta$ | Brightness |
|---|---|---|---|---|---|---|---|---|---|
| | | h | m | s | ° | ′ | | | |
| June | 1.5 | 17 | 56 | 36 | + 23 | 49.9 | | | |
| | 5.5 | 17 | 48 | 4 | 23 | 59.5 | 0.5049 | 0.3858 | 0.040 |
| | 9.5 | 17 | 39 | 43 | 24 | 2.6 | | | |
| | 13.5 | 17 | 31 | 39 | 23 | 59.6 | 0.5189 | 0.4027 | 0.035 |
| | 17.5 | 17 | 23 | 56 | 23 | 50.9 | | | |
| | 21.5 | 17 | 16 | 37 | 23 | 36.9 | 0.5322 | 0.4226 | 0.030 |
| | 25.5 | 17 | 9 | 46 | 23 | 18.3 | | | |
| | 29.5 | 17 | 3 | 23 | 22 | 55.8 | 0.5450 | 0.4444 | 0.025 |
| July | 3.5 | 16 | 57 | 31 | 22 | 29.9 | | | |
| | 7.5 | 16 | 32 | 9 | 22 | 1.1 | 0.5572 | 0.4679 | 0.021 |

## GENERAL NOTES.

We were so much delayed in securing the engraving for this issue that it was impossible to mail sooner. In the time of waiting we thought it best to publish at the same time the first number of Volume IV which is bound in the same cover.

We will issue a number of this publication for the month of August and consecutively each month thereafter, as a large number of our subscribers prefer to have the volumes begin in January instead of September. Ten numbers will constitute a volume as heretofore.

It is not our custom to print long articles in one issue of this publication, because of limited space and the advantages of variety in contents; but the leader of this issue is deemed to be so important in matter and so closely related in all its parts pertaining to the broad field it covers that it ought not to be broken. Furthermore in presenting it with so much excellent illustration we have hoped to mark fittingly the close of the first century since Laplace announced the theory of the nebular hypothesis. Because of the work of George H. Darwin more recently and that of distinguished astronomers in Germany and America, in supplementing the theory of the Nebular Hypothesis, the astronomers of the world will gratefully remember this centennial year.

**Lowell Observatory**.—It is announced that owing to the winter date at which the next opposition of Mars occurs, Mr. Lowell is about to remove his Observatory, including the 24 inch object glass just completed for him by Alvan Clark & Sons, from Flagstaff, Arizona, to near the city of Mexico during the coming autumn. It is further announced that owing to the southern latitude of Mexico, the Observatory, in addition to its regular planetary investigations, especially of Mars, is about to undertake a piece of stellar work. Dr. T. J. J. See of Chicago having temporarly left the University of Chicago to join its staff, for the purpose of making a survey of the southern heavens for the discovery and measurement of double stars and the determination of their orbits.

Dr. See is well known for his general mathematical ability, and in particular for his remarkable work on the theory of double stars and their orbits. His forthcoming book, soon to be published, which deals with his investigations up to the present time, will be the most important contribution yet made to the subject.

**The Alaskan Boundary Question**.—The development of the gold-fields near Juneau adds interest to the question of the boundary line between southern Alaska and British Columbia. As there is a rich gold region, the Cassiar district, just east of Juneau in British Columbia, it is probable that all the intervening country is gold-bearing. Prospecting has thus far been hampered by forest growth so dense that the most experienced woodsman can only make four miles a day. This wealth in lumber, however, must eventually add to the value of the country and render its possession more desirable. Certain Canadian maps, subsequent to 1884, show a boundary line which would cut off twenty-eight thousand five hundred square miles of territory hitherto considered as belonging to the United States. The dispute (if it may be so called) rests on the terms of the convention between Great Britain and Russia, according to which the boundary line,

commencing at the southern-most point of Prince of Wales Island, "shall ascend" to the north along the channel called Portland Channel," etc. As the mouth of Portland Channel is sixty miles east of that cape, the Canadian map makers contend that the line, in order to ascend north from its commencement, must run through the channel immediately east of Prince of Wales Island. A glance at the map suffices to show that this contention is a mere quibble.—From "The Goldfields of Alaska," by Robert Stein, in June *Review of Reviews*.

**The Observatory at Mount Mounier.**—In a recent number of *Nature* we notice an interesting account of the erection of an Observatory on Mount Mounier. This mountain is one of the peaks of the Maritime Alps, and the altitude of the Observatory site is 8,900 feet. The new one is a branch of the Observatory at Nice and was erected in 1893 to verify the discoveries of M. Schiaparelli in regard to the rotation of Venus. Observations were made at both places before Venus reached inferior conjunction of that year and the results were successful. Both the Observatory at Nice and that on Mount Mounier were provided by the generosity of M. Bischoffsheim whose wise and munificent support of astronomy has given him an enviable reputation in Europe and America.

**New Divisions of Saturn's Rings.**—In a late number of *Comptes rendus*, is a report of M. Flammarion that, in the month of April, three new divisions in Saturn's ring had been observed between the Cassini division and the Crape ring thus separating the inner bright ring into four zones. One of the dividing lines was more conspicuous than the other two which were observed with difficulty because of faintness. Such divisions have been observed before, and some of them, if not all, are due probably to the attraction of the planet's satellites. M. Flammarion concludes that the fainter divisions are variable and due to the cause just named.

**Publications of the Washburn Observatory, Vol. IX.**—Professor Comstock, Director of the Observatory has just published an important volume in the series of the Washburn Observatory publications. This volume consists of two parts. The first is an investigation of aberration and atmospheric refraction by himself and the second is by Albert S. Flint, assistant astronomer, and consists of the observations of the right ascensions of 135 stars with the prism apparatus on a 6-inch equatorial. The tables contain the individual observations of the stars, usually on six different nights, and also on six other nights with the circle reversed. The final table gives the results in order of right ascension.

The summary of results in the first part well represents the high grade of astronomical work which Washburn Observatory is doing under the direction of Professor Comstock.

The instrument used was a Clark 6-inch equatorial with a system of reflecting surfaces in front of the objective adapted to measure the distance between two stars separated as far as 120°. The degree of precession gives the probable error of a single observation under normal conditions, as $\pm$ 0″.3 which is less than one millionth part of the whole quantity measured.

"The purpose of these observations was to determine from the annual variations in the distance separating each pair of stars a value of the constant of aberration, and from a comparison of the measured with the computed distances to determine corrections to the refraction tables. The latter part of the pro-

gramme was supplemented by a series of independent measurements of the circumference of the heavens, from which the refraction is to be determined by the condition that the measured circumference plus the refraction must equal 360°.

To conduct these investigations successfully it was found necessary to make special studies of the temperature, aqueous vapor, atmospheric despersion of light of different colors, the refractive index and the coefficient of expansion of air under constant pressure.

The definitive result obtained for the constant of aberration is

$$20''.443 \pm 0''.010.$$

Professor Comstock says that it may be noted as a singular coincidence that if all the corrections for systematic personal error in the observations had been omitted the resulting value of the aberration would have been 20″.499, a value which is very closely the mean of the more recent determinations of the quantity by other methods.

**Mr. Lowell's Unfinished Work.**—Elsewhere will be found an announcement regarding the location and future work of the Lowell Observatory. In this connection it may be said that Mr. John Ritchie in the *Boston Commonwealth* (May 23) has given a good account of the Lowell Observatory, its personnel and its work. One paragraph sets forth views in regard to Mr. Lowell's plan and portions of his work that ought to be repeated. The statement as a whole, is in rather strong language, yet there is truth in it that rightfully belongs to Mr. Lowell. He says:

> It is true that some persons have taken exceptions to Mr. Lowell's plan and to portions of his work, but these, high as may have been the positions which they occupy, have not treated him with the courtesy which one gentleman has a right to expect from another; and instead of criticisms of what he really was doing, they published criticisms of their own interpretation of his plans, which it need not be said was in effect the setting up of men of straw for the pleasure of knocking them down, with no possible relation between the real Mr. Lowell and the man of straw.

**Astronomical Problems of the Twentieth Century** is the title of an address before the New York Academy of Sciences, delivered by its retiring president, Professor J. K. Rees, March 30, 1896. The address is printed in full as a leader in *Science* May 15, 1896. It is a clear and concise statement of what the great astronomers of the world are doing now to solve the problems of their own much loved science. The great work sketched out so admirably will not all be done in the twentieth century.

**The New Astro-Photography.**—We have received a full and interesting letter from David E. Packer, of England, in regard to the new astro-photography which is a further account of attempts to photograph the solar corona without an eclipse. Notices of this work have appeared in this publication during the last two months, and still more will be said about it soon. There are some curious things about the specimen photographs of the corona taken in ordinary sunlight that ought to be very carefully studied by astronomers before the process is abandoned or rejected entirely. This is now being done in some localities.

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